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WHY DO SOME CHILDREN STRUGGLE TO READ?

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Some children have a very hard time learning to read. In spite of normal intelligence and no special hearing or vision problems, they still read very slowly and with many errors. These problems persist even after they become adults: their reading improves with practice but less than that of their peers. This persistent reading difficulty is called developmental dyslexia. It is still not clear what causes dyslexia, and in this article we describe findings from our lab and our interpretation regarding the basis of dyslexia. We found that people with dyslexia benefit less than people without dyslexia from repetition of sounds, and that they behave as if they are less familiar with common syllables and word structures. Using brain scanning equipment, we also found that brains of people with dyslexia "forget" sounds faster. This might be the reason that they do not benefit from repetition as much as people without dyslexia.

LEARNING TO READ

Reading is the process of translating written symbols (such as English letters) into a series of sounds, which are meaningful words. When children first start to read, they need to use sequential deciphering of letters to sounds in order to read words, but after they get some experience, they begin to identify complete words [1]. Representations of verbal words and their meaning exist in children's minds even before they start reading. We know this because children can understand spoken language and speak, long before they learn to read. Most children learn to read at the age of 6–7, but this skill keeps improving and becoming more efficient as children get older.

READING CAN BE A CONTINUOUS STRUGGLE

For some children, learning to read is not simple and can even be very frustrating. About 7% of the kids in regular schools have a very hard time learning to read, even though they do not have special vision or hearing problems and have normal intelligence. These children are born with this difficulty and it will stick with them even when they become adults. This difficulty with reading is a learning disability called developmental dyslexia. People with developmental dyslexia read slower and with more errors than people without dyslexia do. Usually, people with dyslexia also make lots of spelling mistakes, but other than problems with reading and spelling, their abilities in other areas (such as mathematics) are usually perfectly normal (unless they have another disorder). Dyslexia was first described about 100 years ago and since then researchers have been trying to understand how dyslexia causes difficulty acquiring reading skills.

Reading is a complex process that involves vision, hearing, memory, and eye movements. Given that all these are undamaged in people with dyslexia, it is peculiar that they still have such difficulty with reading. It seems that despite the specific characterization of dyslexia, people with dyslexia have additional difficulties, which deviate from reading and writing, and even from the boundaries of language usage.

When learning to read (or reading unfamiliar words) we combine the sounds that the letters represent into a word. When we are required to write a word that we hear, we break it down to speech sounds and translate them to letters. The basic speech sounds are called phonemes. Since people with dyslexia experience difficulties with the process of separating and joining phonemes, many researchers hypothesized that the mental representation of basic language sounds is impaired in dyslexia. About 40 years ago, researchers suggested that the difficulty in dyslexia lies in the ability to process sounds, and is not specific to language [2]. Our experiments were designed to understand this concept more fully.

OUR HYPOTHESIS: DYSLEXIA INVOLVES FASTER "FORGETTING" OF PRIOR KNOWLEDGE

In the last 15 years we conducted a series of experiments with children, adolescents, and adults with dyslexia. A typical experiment is made from some tens of "steps." In each step, the participant hears two sounds with a short time gap (about a second) between them. The participant is asked to decide which sound had a higher pitch, the first or the second. In experiments of this type, participants feel that they are comparing the two sounds, and that is how they decide. However, it turns out that sounds from previous steps also influence the decision: our internal representation of the pitch of the first sound in the current step becomes similar to previous sounds we heard, in previous steps. For example, if we hear a sound with a high pitch now, but most of the previous sounds were with low pitch, our representation of this sound will be a bit lower, it will be "pulled down." We discovered that this effect is smaller for participants with dyslexia [3]. Following this, we hypothesized that people with dyslexia have difficulty with accurately storing the sounds that they hear in memory. Such storing is essential for efficient reading.

In order to test the hypothesis that sound memories decay faster in the brain of people with dyslexia, and to understand in which brain areas this faster decay occurs, we conducted another experiment. In this experiment, participants were scanned in a device called a functional magnetic resonance imaging scanner (**fMRI scanner**) while performing the same task of listening to sounds and determining which has a higher pitch. The fMRI allowed us to record the activity of the participants' brain during the experiment.

Generally, when the same sound is presented twice with a short gap in between, the brain's response to the second presentation is smaller. This phenomenon is called neural adaptation. The smaller response to the second sound tells us that the brain still remembers the first sound in some way, because the first sound still influences the processing of the second sound. In people with dyslexia, we found that this period of subconscious memory of the first sound was shorter. When the gap between sounds was 10 s, the response to the second sound measured in the brains of people without dyslexia was smaller, telling us that the memory of the first sound was still stored in their brains. In contrast, people with dyslexia had a full-intensity response for the second sound if the sounds were 10 s apart, telling us that their brains no longer had available memory of the first sound. This difference in memory duration was observed in multiple areas of the **cortex** [4] (Figure 1).

fMRI (FUNCTIONAL MAGNETIC RESONANCE IMAGING) SCANNER

A device using magnetic fields to measure brain activity when the participant is performing different tasks. The measurement is based on the amount of oxygen in the blood flowing in the brain during the task. During the experiment, the participant lies inside a tube-like structure and performs the required task, while the oxygen levels are measured. The measurement is non-invasive and that is why it is very common in the field of neuroscience.

CORTEX

A part of the brain, its outer layer. The cortex processes auditory (sound) and visual information, deals with problem solving, sending movement messages to the muscles and much more. The cortex is folded, and thus is full of ridges and grooves, which greatly enlarge its surface area. The cortex is divided into a few sub-areas according to the grooves, and these sub-areas are related to different functions.

PEOPLE WITH DYSLEXIA LEARN MORE SLOWLY FROM REPETITION

The main problem faced by most people with dyslexia is reading words. How is this problem related to the difficulty we discovered with memory of sounds? It is possible that for people with dyslexia, the fast memory decay makes the accumulation of knowledge slower. Figure 2 illustrates this idea. Generally, the more we are exposed to

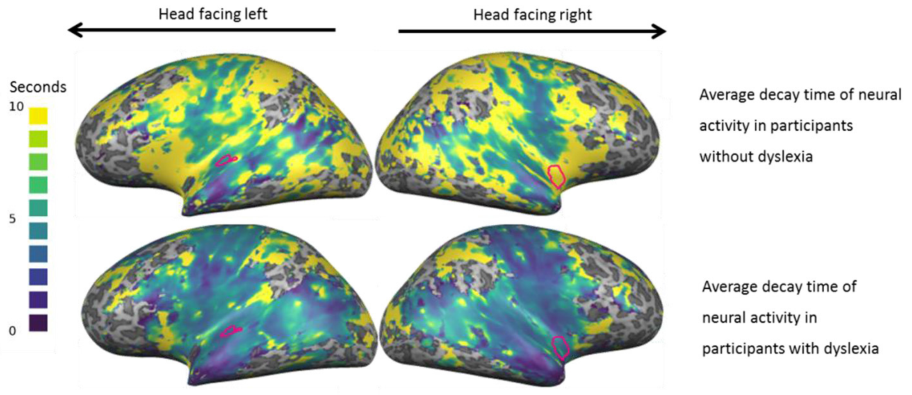

Figure 1

Figure 1

People with dyslexia have a faster decay of sound memories than people without dyslexia. The right and left sides of the brain's cortex are shown for readers without dyslexia (top row) and readers with dyslexia (bottom row). The human cortex is folded, and thus, in order to see the neural activity taking place at the depth of the folds, the folds in this figure were "straightened" outwards and it looks as though the brain is smooth, and the folds appear in dark gray. The colors represent the length of time that sound memories last in the brain (see scale on the left). You can see that the brains of readers without dyslexia have more yellow in many areas of the cortex, meaning that memories lasted longer in the brains of these people than in the brains of those with dyslexia. This difference was particularly strong in a relatively small area which is related to auditory processing (marked with a red contour), probably because that area is strongly involved in the task that the participants performed (deciding which sound has a higher pitch).

MORPHOLOGY

The branch of language research that studies the structure and components of words and how components are combined into whole words.

something, the more we improve our performance in tasks related to this exposure. But, for people with dyslexia, the learning curve for things they were previously exposed to is slower. Examining the differences in performance between the two groups in Figure 2 shows that although people with dyslexia continue to learn with repeated exposure, the difference between the performance of the two groups will become bigger as the amount of exposure increases.

EFFECTS ON LANGUAGE SKILLS: PEOPLE WITH DYSLEXIA BENEFIT LESS FROM WORD AND SYLLABLE FAMILIARITY THAN PEOPLE WITHOUT DYSLEXIA

We use language throughout our lives, and most of us learn the rules and structure of language automatically and subconsciously. In our experiments, we used the structure of language and the rules about how word parts are put together, which is called **morphology**, to study differences between people with dyslexia and people without it.

In Hebrew, all verbs have one of a few specific structures, and every other form is "illegal" in the language, so readers are never exposed to those non-existing forms. For example, the word *lagadnu* is not a real word in Hebrew, but it is very similar in structure to the real words *katavnu*, *pagashnu*, and *kalatnu*. On the other hand, the word *hukshimti* is also not a real word in Hebrew but, unlike *lagadnu*, there are no Hebrew words that share its structure, so it is less familiar to native Hebrew readers.

We examined whether reading speed is influenced by familiarity with word morphology. Students without dyslexia read made-up words that had a structure that was similar to that of real words faster and more accurately than they read words without a familiar structure. This is to be expected, because words with familiar structure require less "work" from the brain—they do not have to be processed letter-by-letter. However, for students with dyslexia, there was no

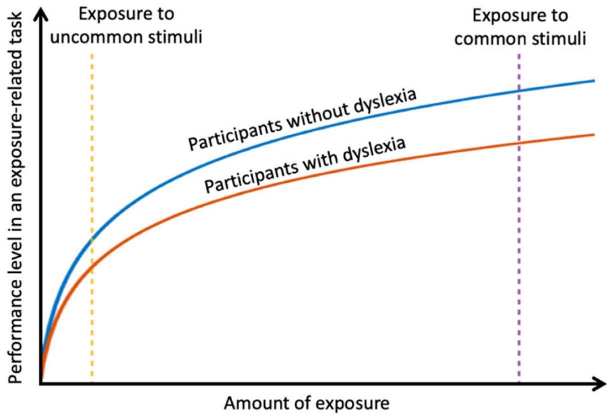

Figure 2

Figure 2

Learning from previous exposure. An illustration of learning curves of people with and without dyslexia according to the amount of exposure to stimuli (such as syllables or words). Both for people with and for people without dyslexia, larger exposure results in more reliable internal representations and subsequently better performance. However, we hypothesize that the learning curve of people with dyslexia is slower, meaning that as exposure increases, the difference in performance between the groups increases as well.

significant improvement in speed or accuracy of reading made-up words with Hebrew morphology compared with words that had no familiar structure [5]. These results tell us that morphology does not assist people with dyslexia in reading as much as it assists people without dyslexia.

When we used units that are smaller than words, we found similar results. Words are constructed from syllables. The word *grandfather*, for example, is constructed from three syllables: *grand-fa-ther*. The syllable *ther* is frequent in English, it appears in many words. In contrast, there are non-frequent syllables, such as *lus* (the third syllabus in the word *stimulus*). It is known that syllable frequency has a big effect on the success rate when participants are asked to repeat series of syllables that were presented to them. In accordance with this, in our experiment participants repeated series of frequent syllables more accurately than series of less frequent syllables, but this advantage of syllable frequency was significantly smaller for participants with dyslexia [6]. These results tell us that syllable frequency does not enhance the memory of people with dyslexia as much as it enhances the memory of people without dyslexia. Thus, people with dyslexia have a reduced benefit from repetition of syllables and of word structures, similarly to their reduced benefit from repetition of simple sounds, and subsequently their performance is not as good as of people without dyslexia. The exposure of participants with dyslexia to syllables and words is similar to the exposure of participants without dyslexia, but participants with dyslexia gain less from this long-term exposure, as illustrated in Figure 2.

SUMMARY

Developmental dyslexia is a specific learning disorder which hinders the acquisition of reading skills. Researchers have been searching for the cause of dyslexia for many years, and in this article we suggest that the main difficulty in dyslexia is less efficient usage of prior knowledge about stimuli that were already presented, due to a faster decay of memory for these stimuli. We based this idea on results of experiments with simple sounds and brain activity. We also compared the accuracy and speed of reading words with and without a familiar structure, and the memory of frequent vs. infrequent syllables. These data help us to understand the cause of dyslexia, and an understanding of the cause might eventually help with treatment. Although dyslexia persists throughout a person's life, interventions can improve the abilities of people with dyslexia and, in general, the earlier the interventions take place, the more effective they are.

ORIGINAL SOURCE ARTICLE

Jaffe-Dax, S., Kimel, E., and Ahissar, M. (2018). Shorter cortical adaptation in dyslexia is broadly distributed in the superior temporal lobe and includes the primary auditory cortex. *eLife* 7:1–9. doi: 10.7554/eLife.30018

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

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We are seventh grade gifted students class at Hakfar Hayarok—Youth village for environmental leadership. We study with students with shared interests, enrich our knowledge in various and diverse fields, we are exposed to content in science and the humanities and enjoy very high level of learning.

AUTHORS

EVA KIMEL

During my Ph.D. I have studied how regularities and repetitions in language assist people with and without dyslexia in learning and memory tasks. Ever since I remember myself, I was curious about how we learn, remember, understand, and process the information coming from the world around us. I am still very curious about that, and lately also inspired by the way that my daughter studies the world. I also like some things that are not directly related to science, such as chocolate balls and Zumba. *eva.kelman@gmail.com

MERAV AHISSAR

I am a professor at the Hebrew University of Jerusalem. The research in my lab focuses on auditory processing, learning, and memory in adults and children, and special populations—people with dyslexia and people with autism. We use behavioral experiments and measure neuronal activity using EEG and fMRI. The goal of our studies is to understand these processes in depth and describe them computationally for the regular population as well as for special populations.