frontiers FOR YOUNG MINDS

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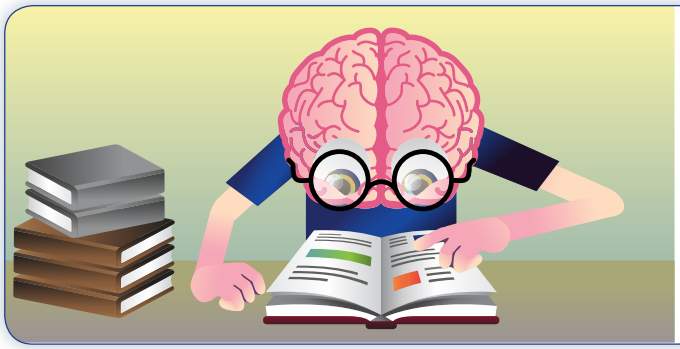

The reading brain

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Do you enjoy reading books? Reading is one of the unique activities that only humans do, and we have not been doing it for that long! Humans have talked to each other using a language system with grammatical rules for at least 100,000 years, but we have been reading and writing only for a few thousand years! What happens in our brain when we read? Our brain has developed a region that is specialized in knowing what written words look like. It closely works together with other parts of the brain that help us understand words and to speak. Importantly, as we learn to read, this region will become trained in recognizing word shapes used in whatever language we train it with.

Do you enjoy reading books? Reading is one of the unique activities that only humans do, and we have not been doing it for that long! People have been practicing spoken communication using a language system with grammatical rules for at least 100,000 years. We have been building tools for even longer, with the first stone tools dating back about 2.5 million years [1]. But we have been reading and writing only for a few thousand years!

Writing was invented in Southern Mesopotamia, or present-day Iraq, by the Babylonians around 5,400 years ago (Figures 1 and 2) [2]. Back then, only a few people could read and write. Nowadays, these skills are taught in schools and are accessible to a lot of us. However, there are still many people in the world – children and adults alike – who never had the chance to learn to read and write. Not knowing how to read or write is called *illiteracy*. Today, about 1 in every 10 people on our planet cannot read or write. That means nearly 800 million of us are illiterate!

What happens in our brain when we learn to read?

THE WORDBOX IN OUR BRAIN

About a third of our brain is specialized in analyzing things that we see. This part of the brain is also known as the visual system. This system is based in the *cortex*, the folded surface of the brain. Areas of the visual system lie in occipital cortex (red in Figure 3) and parts of temporal (yellow) and parietal (green) cortices.

Other parts of the brain help us understand and produce language (to speak). These parts are located mostly in the left *hemisphere*, or the left half of the

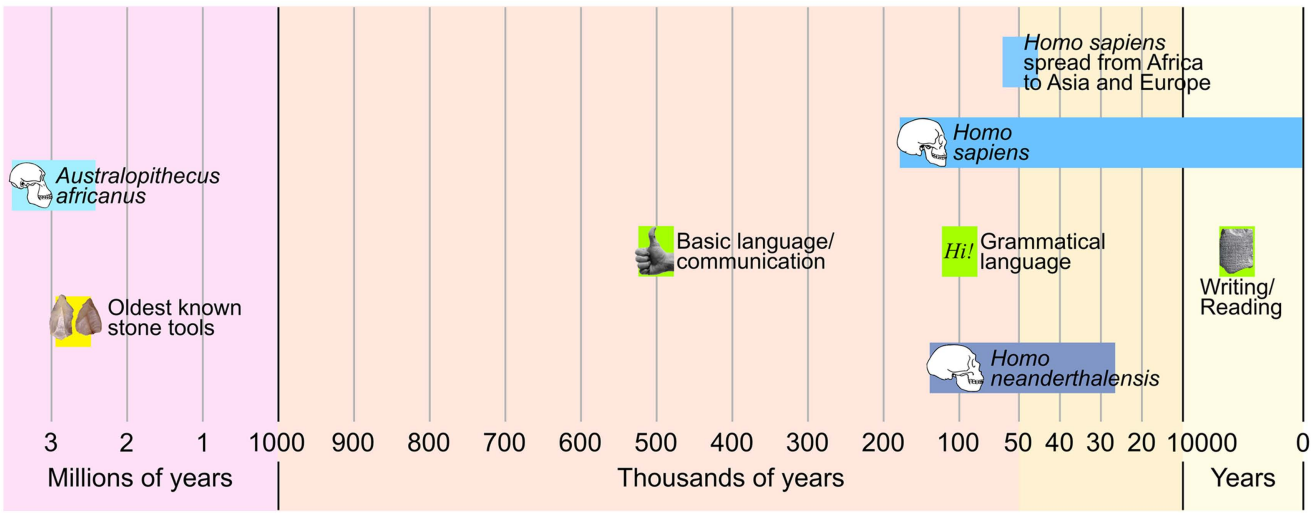

FIGURE 1 - Timeline of language evolution.
Reading and writing are relatively new abilities of the human species: while we have been using tools for more than 2.5 million years, we have only started communicating with each other about half a million yeas ago. The use of systematic languages following grammatical rules that we use to talk to each other started only about a hundred thousand years ago, and reading and writing only started in the last few thousand years!

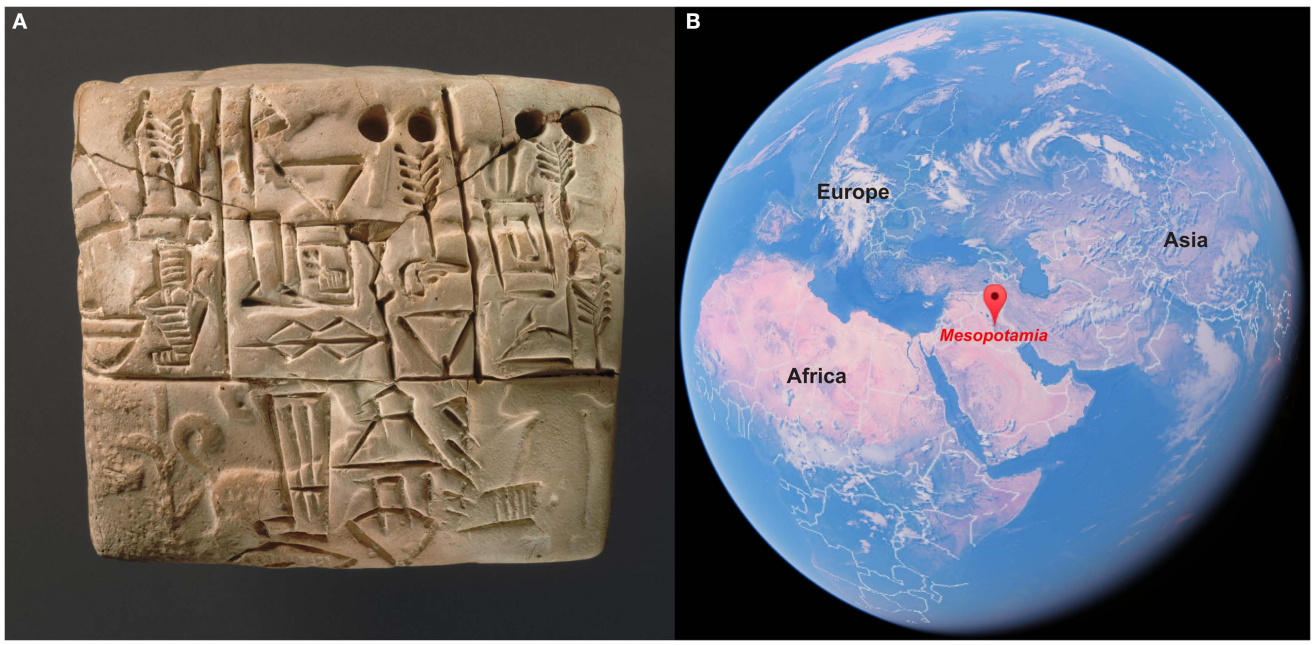

FIGURE 2 - A. Sumerian cuneiform tablet, ca. 3100–2900 B.C.
Writing, and thus reading, was invented about 5,400 years ago in Mesopotamia (present-day Iraq), where this clay tablet is from. Early writing was used primarily to record and store information pertaining to the trading of goods. Signs were drawn with a reed as a writing utensil on pillow-shaped tablets, most of which were only a few inches wide. The reed left small marks in the clay which we call cuneiform, or wedge-shaped, writing. This tablet most likely documents grain distributed by a large temple. The seal impression depicts a male figure guiding two dogs on a leash and hunting or herding boars in a marsh environment (image from The Metropolitan Museum of Art, Purchase, Raymond and Beverly Sackler Gift, 1988, www.metmuseum.org. http://metmuseum.org/Collections/search-the-collections/329081).
B. Globe showing the approximate location of Mesopotamia in present-day Iraq. Adapted from Google Earth, https://www.google.com/earth/.

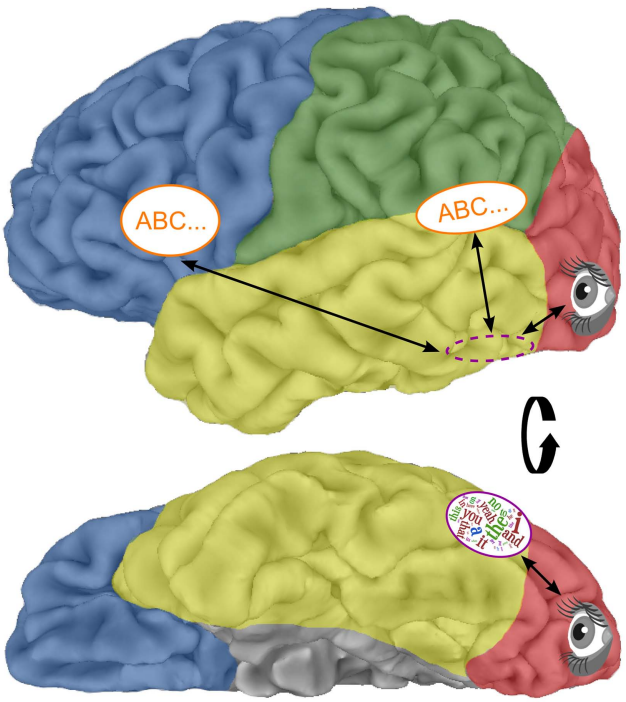

FIGURE 3 - The wordbox in our brain.
The upper part of the image shows the left half of the brain, also called the left hemisphere, in a view from the side. The lower part of the image shows that same left hemisphere from a bottom view. The cortex (the folded surface) of the human brain is divided into four parts: the occipital cortex (red), the temporal cortex (yellow), the parietal cortex (green), and the frontal cortex (blue). Things that we see are analyzed in the visual system located in the occipital cortex (marked with an eye icon) and in parts of the temporal and parietal cortices. The human brain has developed regions that are specialized for language information. Words we speak or comprehend are processed in the regions marked with orange ovals. The wordbox or visual word form area used for recognizing the shapes of words we look at is marked by the purple oval. It can only be seen when looking at the brain from the bottom. The dashed purple oval marks where this area would be if you could see it from the side. The wordbox acts as a translator between our visual system and our language regions.

brain. Regions for understanding language are found in left temporal cortex, and regions for producing language are found in left frontal cortex (Figure 3). When we read, both the visual system and the language regions are involved: The visual system examines what the words look like, and the language regions tell us what they mean.

A third part of the brain links the visual system and the language regions together. We will call this region the *wordbox*, but it is also known as *visual word form area* (Figure 3) [3]. This area of the brain translates visual shape information (what words look like: a string of round symbols with straight lines) into meaningful information that our language regions can understand and further work with. Basically, the wordbox is a brain region that is specialized in knowing what written words look like.

Is the wordbox already in our brain when we are born or is it only there after we learn how to read? And do illiterate people (who cannot read) have it?

HOW THE WORDBOX DEVELOPS IN THE BRAIN

How does the brain build a wordbox? Before you learned to read, you didn't know that words and letters were symbols for sound – your brain just saw them as squiggly shapes. An "O" has a round shape. So does an orange or a basketball. Shapes of any sort are stored in a region of the brain called the *object cortex*, which is part of the temporal cortex in the visual system (Figure 4A). This region can tell an O, an orange, or a basketball apart, even though they all have similar round shapes. The object cortex also provides information about the purpose and meaning of different things in the world: you eat an orange but not a letter or a basketball!

Thanks to the object cortex, we can also recognize different shapes and objects no matter how we look at them. For example, we can recognize a basketball hoop from afar when entering the gym or from close by when standing directly underneath. Even if the hoop were turned upside down, we would still know what it was (Figure 4B)! Our object cortex identifies it as the same hoop at all times.

However, think about the letter "d." The same shape flipped is a "b" or turned upside-down a "q." In all of these cases the shape stays the same, but once we learn the alphabet, the meaning and use of the letter changes. Our visual system has to be very precise about recognizing a "d" as a "d" and not turning it accidentally into a "b" or a "q."

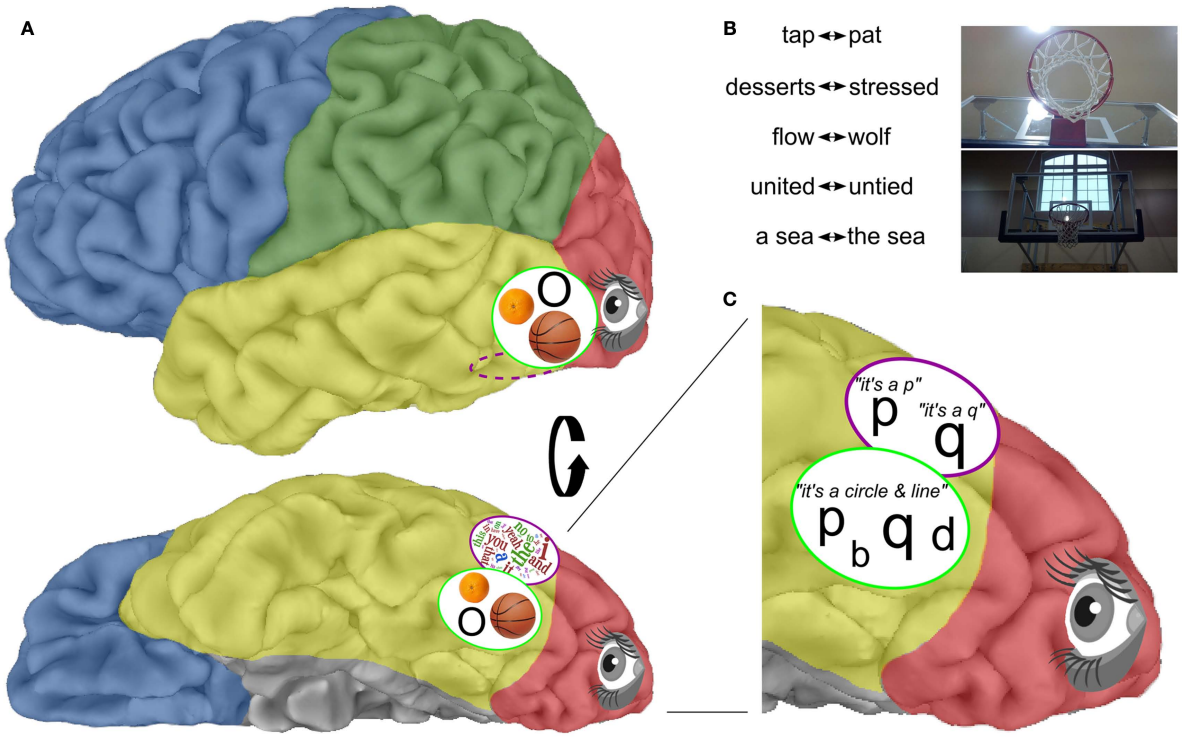

FIGURE 4 - A. The object cortex (green oval), which is located close by the wordbox (purple oval), helps us recognize objects. For example, it can tell apart different objects that have a similar shape, like an orange, a basketball, or the letter "O."
B. Strings of letters have different meanings based on their order, even though they look similar. For example, "tap" is "pat" if we arrange the letters backwards, or "united" becomes "untied" if we move the letter "t." On the other hand, we can recognize a basketball hoop when we look at it from the front or when standing underneath it, even though it looks very different in those two cases.
C. The object cortex recognizes shapes or objects (like a basketball hoop) no matter from what viewpoint we look at them. The wordbox, on the other hand, can discriminate between the same shapes (in this case letters) that form different words in different arrangements. For example, the object cortex will recognize a "p," "q," "b," and "d" as the same shape (a circle with a straight line attached) while the wordbox will discriminate between the four different letters.

When we first start learning to read, the wordbox develops from the object cortex and is still able to recognize the same shapes from all viewpoints – you can write reversed, you are able to read upside-down, and so on (Figure 5). Over time, the wordbox learns that the order of letters is important because it defines words – for example, "pat" and "tap" mean different things (Figure 4B). That is why it is important to always read English from left to right and not from right to left!

The wordbox learns what words typically look like and it starts to follow rules that go along with a given language, like the example of reading from left to right. The wordbox is a region in the brain that develops as we learn to read, and it gets trained to

FIGURE 5 - Example of handwritten text written backwards.
Here you can see the handwriting of a 5-year-old kid with some letters written forwards and some written backwards. For example, the name "BEN" is written backwards.

recognize shapes that look like words. It recognizes letters and shapes precisely as they appear and in which sequence they happen to occur with other letters (Figure 4C) [4]. While the object cortex will recognize a "p," "q," "b," and "d" as the same shape (a circle with a straight line attached), the wordbox will discriminate between the four different letters!

So if you are an experienced English reader, your wordbox will be active while you are reading this article. What if this text was in Chinese and you could not read Chinese?

THE WORDBOX IS SHAPED BY WHICH LANGUAGE YOU READ

Your wordbox will be most active when you look at words written in letters from the language you are most used to. However, across different cultures and languages, the wordbox develops in the same part of the brain. So when a Chinese-speaking person

FIGURE 6 - Training the wordbox by reading.
Across the world, the wordbox forms in the same region of the brain, no matter what language a person learns. Once a person learns to read and write, the wordbox is shaped by experience in reading words in a certain language, just as your arm muscles shape up the more often you lift weights.

reads in Chinese, and when an English-speaking person reads in English, the same part of the brain, the wordbox, will be active (Figure 6). In fact, even people who are born blind and learn how to read by touch (called Braille reading) have a wordbox that is in the same part of the brain as in seeing people.

Our brain is shaped by the experiences that we make throughout life. There is a part of our brain – the wordbox – that is prepared to recognize word shapes, and as we learn to read, will become trained in recognizing word shapes in whatever language we use to train it [5].

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Riverside Elementary School

Riverside Elementary School serves children from prekindergarten through fifth grade in Princeton, NJ, USA. Our diverse student body includes children from more than 23 different countries, and we all love to learn about brain! We also have a science lab, a courtyard with frogs and box turtles, a team of dedicated teachers and support staff, and a great principal who always supports new opportunities for learning. Fourth grade students are either in Ms. Levy's or Mr. McGovern's classroom, and Mr. Eastburn is their teacher in the science lab.

AUTHORS

Tanja Kassuba

I study how our brain recognizes objects that we see, hear, or touch (or smell!) and how our brain enables us to use objects as tools. Outside the lab I like to hang out with my friends and play with my friend's dog Renny (see photo) or my nieces. I also love looking at colorful photos from National Geographic, and my favorite animals are sharks.

Sabine Kastner

Scientist and Professor, she studies how people use their brains to pay attention to specific activities (e.g., how can it be that you do not hear your parents calling for dinner when you play a videogame or read a book). Sabine also enjoys spending time with her two kids and loves the Beatles.