# How did your brain just read this sentence?

Communication, in any form, is necessary for the survival of any species. Nature has evolved over centuries to develop increasingly complex modes of communication: starting from chemical/electrical signals (found in cells/simple organisms) to more complex use of actions and sounds (found in all animals including humans). However, the information is often lost/manipulated when transmitted over speech. Around ~5400 years ago, humans developed a new form of communication in the form of symbols (or scripts). This system helped us preserve information in its intact form over generations that was not possible earlier.

In an evolutionary timescale, 5400 years is a brief time for our brains to have evolved to process written text immediately after birth. Hence, we spend a lot of time in schools to master this new mode of communication i.e. learning to read scripts. We start by recognizing letters, reading them one at a time. Over time, we become proficient readers and are able to read an entire word at a glance. But how does the human brain perform such an amazing feat? where does it all happen in the brain? Answering these questions will require us to peek inside the brain of people who are fluent readers and contrast it with the brains of people who cannot read that language. We need to also ensure that this comparison is not confounded by other factors like age, cognitive abilities, social-economic status, literacy level etc. Such a comparison has proven to be difficult in the past because, in the Western world, nearly all languages rely upon the same Latin letters.

Fortunately, our ancestors developed different scripts for Indian languages while preserving the phonetic sounds across alphabets. Such diverse writing system is a boon for a neuroscientist who can now study the effect of reading expertise by comparing the brains of readers and non-readers of a given script. At Vision Lab, Indian Institute of Science, we performed a series of behaviour and brain imaging studies to tackle this problem. Before revealing the secret code used by our brain to read, let me take you through the adventure land of experimental neuroscience and help you find answers by introspection.

Indian Institute of Science (IISc) attracts students from all over India and a few among them visit South India for the first time. Imagine you are one of them. Now, as soon as you land in Bengaluru, you will encounter a lot of signboards in the local language, Kannada. Not only will you not be able to read them, but you will also have a tough time differentiating one letter from the other. This is true for any unfamiliar languages like Malayalam, Chinese, etc. In contrast, people familiar with these scripts will not have any such issues. Hence, as you would have rightly guessed, learning to read makes the letters of a script appear different from each other.

Like any other scientific argument, we need to prove our intuition by measuring the similarity between single letters. But how do we do that? One approach is by asking people to rate the visual similarity between shapes, say, letter ‘A’ and ‘B’ on a scale of 1-10. What rating would you give? Answering this question is not at all obvious and the responses will be highly variable across people. But it is obvious that ‘O’ and ‘Q’ are visually more similar than ‘O’ and ‘X’.  Hence, this approach allows us to systematically rank the similarity between two shapes (although only for extreme examples) but not quantify them. Alternatively, we can use a visual search task. It is a very natural task that we perform in our day-to-day life. We all search for things in a crowded scene, some of them are easy to find and while others are not. Imagine standing in a parking lot, it will take a lot more time to spot your car if it is surrounded by other cars compared to when it is surrounded by bikes. This is because each car is more similar to other cars compared to bikes. Here, the object of interest is your car (target) and the surrounding vehicles are distractors. Hence, the amount of time taken for the search can be used as a measure of visual similarity between the target and the distractors. The inverse of this search time gives us a dissimilarity measure that serves as a proxy for the difference in the brain activity evoked corresponding to any two shapes. Thus, visual search is a very natural task to quantify similarity and it can be performed by both readers and non-readers alike.

In this study, we chose participants who were fluent in either one of the two Indian languages: Telugu and Malayalam. These languages have visually distinct scripts and often people familiar with one of these languages do not know the other. Volunteers performed a visual search task involving letters from both known and unknown script. As expected, it is easy to find the target from a known script. Any difference in response time between readers and non-readers could also be attributed to the cognitive abilities of each group. Hence, to rule out any such possibilities, we showed this effect in both groups. Next, we asked if reading expertise makes all the letter pairs equally dissimilar? The answer is NO. Observe that even in English, searching ‘O’ among ‘Q’ will still be harder compared to ‘O’ among ‘X’ irrespective of how fluent you are in English. Hence, reading expertise does not fundamentally alter the default representation of letters in the brain (as evident in non-readers). It relatively increases the dissimilarity between letters, thereby decreasing confusability.

This observation made at the single letter level is valid even for words. But how does our brain encode longer strings? Are they just a combination of letters in a specified order? Or do we develop a separate detector for each word? If latter, then we should not be able to predict the response for a given word using its single letter responses. Further, any model of word recognition should also explain our ability to read jumbled words. Consider the paragraph below that you might have all seen on social media

"aoccdrnig to a rseearch at cmabrigde uinervtisy, it deosn't mttaer in waht oredr the ltteers in a word are, the olny iprmoetnt tihng is taht the frist and lsat ltteer be at the rghit pclae. … huamn mnid deos not raed ervey lteter by istlef, but the wrod as a wlohe."

It is tempting to think that we identify words as a single unit but if you observe carefully, this is certainly not true. It is easier to read 'unievrsity' compared to 'utisreviny' even though the first and last letters are the same. Also, letters are not necessary to form a word; one can easily read 7EX7 W17H NUM83R5. Intuitively, it is because '7' is visually similar to 'T', '5' is similar to 'S' and so on. Thus, the code of word recognition should account for both visual similarity between symbols and position information. Apart from this, the code should also account the effect of neighbouring letters. This effect is analogous to the electromagnetic forces/interaction experienced by charged particles when placed in close vicinity of other particles. Using computational models, that accounted for each of these ingredients, we were able to fully understand the visual representation of strings in our brain.

The prediction of this letter-based model did not deviate for both readers and non-readers. Only the interactions between the neighbouring letters decreased for the readers of a given script. This mechanism extends even at word level i.e. it is easier to read '*Siberiancrane'* than its scientific name '*Grusleucogeranus'* because of the weaker interactions between two familiar words. Thus, we hypothesize that the brain uses this strategy to process all the letters of a word in parallel, thereby improving reading efficiency and giving us the percept of reading words as a whole. This is one case where the data-driven approaches surpass intuition and help us to decode the rules used by our brains. Using brain imaging techniques such as fMRI (functional Magnetic Resonance Imaging), we were able to peek inside the brain and localized these effects in higher visual cortex.

The insights gained over this journey could help us understand the issues faced by dyslexic children and developed idiosyncratic remedies to help them read fluently. Also, understanding the human brain could help us build better Optical Character Recognition (OCR) algorithms such that next time you encounter a new script, your electronic device will accurately convert it into your native language.

Aakash Agrawal
Indian Institute of Science
aakash@iisc.ac.in