

Is the brain prewired for letters?

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Even before a child learns to read, the future location of his or her letter-processing area can be predicted from its connections to the rest of the brain. Reading acquisition thus piggybacks on a pre-existing brain circuit.

How do we read? In the past 25 years, thanks to brain-imaging methods, the mechanisms of reading have begun to be elucidated (Fig. 1). A key site is the visual word form area (VWFA), a brain region of the left hemisphere that systematically activates, at roughly the same brain location in the left occipitotemporal sulcus, whenever we see a written word¹. There is considerable evidence that this region plays a crucial role in the visual component of reading in all cultures throughout the world. In any good reader, a few minutes of functional MRI suffice to isolate it as a set of voxels in the left ventral visual pathway that respond more to strings of letters than to other visual stimuli such as objects or faces. This response is clearly the outcome of reading acquisition because it is undetectable in illiterate individuals or in young children who haven't yet learned to read, and its activation tightly correlates with reading performance. Its fast emergence in the course of reading acquisition is one of the main biomarkers of literacy².

The reproducible localization of the VWFA is puzzling, however. Writing is a very recent invention: it is generally believed to have emerged approximately 5,400 years ago in the Middle East, with the alphabet itself being only about 3,800 years old. Those times are far too short for Darwinian evolution to have shaped our genome for reading—so why do our brains seem to dedicate an area to it?

In this issue, Saygin *et al.*³ offer a solution to this puzzle. By scanning the same children twice, first at the age of 5, before schooling, and then at the age of 8, when the VWFA is in place, they show that one can predict, 3 years ahead, where reading will land—not just the average location of the VWFA, but its precise position and contours, unique to each child. It is the pattern of connectivity with the rest of the brain, and particularly with areas of the left temporal lobe, that predicts which voxels will

make up the VWFA. Thus, reading piggybacks on a pre-existing pathway.

Earlier efforts to explain the consistent localization of the VWFA focused primarily on its topographical relation to other functional areas of the ventral visual cortex. It was discovered early on that the VWFA is part of a systematic functional map. In adults, the VWFA lies several centimeters lateral to regions that preferentially respond to places and next to voxels that respond to faces (the so-called fusiform face area, or FFA, which is present in both hemispheres, although typically larger in the right). Those findings led to a simple suggestion: both reading and face recognition would encroach upon a part of the visual cortex that processes high-resolution foveal details. Indeed, the ventral visual pathway is traversed by a major retinotopic gradient that extends well beyond the occipital cortex. Foveal images preferentially activate the lateral sectors of ventral visual cortex, where the VWFA and FFA are located. Such a bias might

explain why the FFA lands at a systematic place in relation to this retinotopic gradient⁴.

Other functional properties of the ventral visual cortex, such as a preference for line junctions, might also pre-date the acquisition of reading, and even explain why specific shapes such as T and L are systematically selected as letters^{1,5}. Even in the monkey, different sectors of the ventral visual cortex preferentially recognize different types of shapes⁶. Such pre-existing functional properties would make the VWFA site ideally suited for recognizing the high-resolution shapes of letters and letter strings, thus biasing it for reading acquisition.

Two recent findings, however, raised problems for this feature-based view of the origins of the VWFA. First, there was the discovery of a visual number form area (VNFA), a cortical region highly responsive to the sight of Arabic numerals but not of letters⁷. This region lies at least 1 cm lateral and slightly anterior to the VWFA site. Numbers and letters possess very similar visual features, so a shape bias cannot

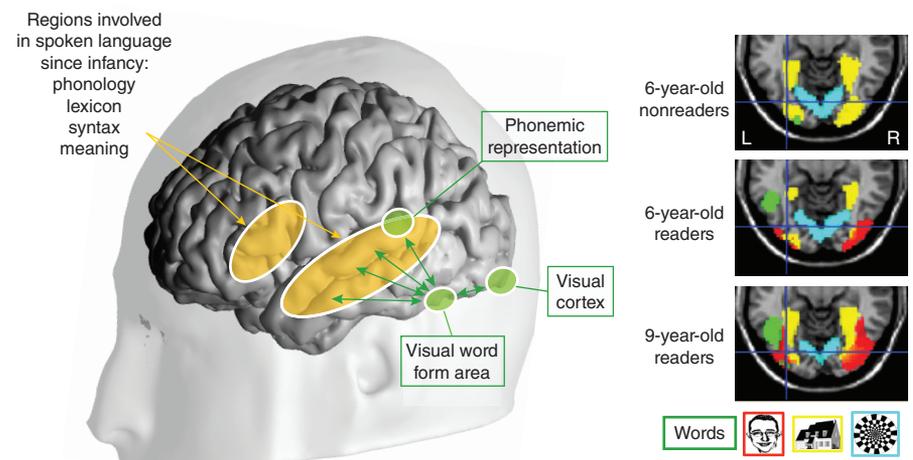


Figure 1 A simplified picture of reading acquisition. Spoken language acquisition starts in infancy, using dedicated networks of left-hemisphere temporal and inferior frontal regions. The acquisition of literacy consists in creating a new visual input pathway into this language network (left). The emergence of the VWFA is a major correlate of literacy. This region, which lies at the base of the left occipitotemporal pathway, develops a preferential response to written words once a child learns to read (green area at right). Saygin *et al.*³ now demonstrate that, even in preliterate children, the future location of the VWFA can be anticipated: where reading will 'land' can be predicted by examining each voxel's connectivity pattern, particularly with left-hemispheric areas frequently involved in language processing. Bottom right functional MRI image adapted from ref. 14, Elsevier; top right and middle right functional MRI images from Monzalvo Lopez, A.K., *Etude chez l'enfant normal et dyslexique de l'impact sur les réseaux corticaux visuel et linguistique d'une activité culturelle: la lecture*, PhD thesis, Univ. Paris 6 (2011).

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be the explanation for their distinct cortical localizations. Second, a VWFA was found, at its usual cortical location, in blind subjects, whether they were reading in Braille or using sensory substitution in the auditory modality (using an algorithm that converts visual shapes into synthetic spatiotemporal sound patterns)⁸. This finding seems to rule out any explanation based on visual features: the so-called ‘visual’ cortex must, in fact, possess abstract properties that make it appropriate to recognize the ‘shapes’ of letters, numbers or other objects regardless of input modality.

In response to those two challenges, an alternative theoretical proposal emerged: perhaps the VWFA owed its properties to constraints arising from its connectivity with other brain areas⁸. The VNFA would connect to parietal cortex, where quantities and math are processed, while the VFVA would connect to temporal and inferior frontal cortex, where spoken language is processed since birth⁹. This theory seemed all the more plausible since previous research, also by Saygin *et al.*¹⁰, had already shown that the specific localization of the FFA could be predicted by its connectivity pattern. In the case of reading, although there were no developmental data, examination of the anatomical connectivity of the VWFA in adults was consistent with this hypothesis: this region, unlike the FFA, does indeed preferentially connect to left-hemisphere lateral temporal and inferior frontal areas where language processing is often found¹¹.

Brain connectivity in adults, however, could be the outcome of reading acquisition rather than its precursor. To genuinely test the hypothesis that the VWFA owes its specialization to a pre-existing connectivity pattern, it was necessary to measure brain connectivity in children before they learned to read. This is what Saygin *et al.*³ now report. They acquired diffusion-weighted images in children around the age of 5 and used them to reconstruct the approximate trajectory of anatomical fiber tracts in their brain. For every voxel in the ventral visual cortex, they obtained a signature profile of its quantitative connectivity with 81 other brain regions. They then examined whether a machine-learning algorithm could be trained to predict, from this connectivity profile, whether or not a voxel would become selective to written

words 3 years later, once the children had become literate. Finally, they tested their algorithm on a child whose data had not been used for training. And it worked: prior connectivity predicted subsequent function. Although many children did not yet have a VWFA at the age of 5, the connections that were already in place could be used to anticipate where the VWFA would appear once they learned to read.

The results strongly support the connectivity hypothesis. They also fit with much recent evidence that the main cortical fiber tracts are already in place in infants¹², possibly explaining why infants already exhibit various forms of functional specialization, particularly for spoken language¹³. However, they also leave open many interesting questions. Can early connectivity also explain the existence of a VNFA? How narrow are those initial connections? Do they single out a precise cortical location, or do they operate more like a partial bias that combines with other preferences such as a penchant for foveal shapes? Do these connections operate in both directions, such that a preliterate child may already activate his or her VWFA during spoken language processing? Above all, what is the function of vision-to-language connections before reading? One possibility is that spoken language processing benefits from visual inputs from face- and body-responsive visual areas, since facial and limb gestures strongly correlate with speech utterances^{8,14}, but this hypothesis is speculative, and Saygin *et al.*³ did not find any evidence that face responsivity predicts reading selectivity. Face and word processing occupy distinct cortical locations, although they are close enough that the growth of one seems to induce the shrinking of the other².

Although those questions remain, the present data nicely dovetail with the ‘neuronal recycling’ view, whereby the acquisition of literacy takes advantage of a pre-existing cortical circuit which it repurposes for written word recognition¹. The child’s brain possesses just the right type of prior circuitry, plastic enough to support the acquisition of arbitrary symbols for phonemes and words, and our culture has learned to exploit it. What might happen if these connections are missing or weakly developed? Could this hypothesis explain some forms of dyslexia that might be detected

before a child enters school? Or is brain plasticity sufficient to circumvent this difficulty; for instance, by using homologous areas of the right hemisphere¹⁵?

More philosophically, perhaps, if the brain did not evolve for reading, maybe we should consider the opposite possibility: in the course of cultural evolution, our writing systems may have evolved to accommodate the preferences of this language-connected region of visual cortex. As one of us wrote¹, “if there is any truth to neuronal recycling, our genetic make-up severely curbs the set of writing systems that can be learned. This prediction leads us to question the apparent boundlessness of cultural diversity. If we scratch the surface of the more obvious superficial cultural variations, we should uncover evidence for universally shared deep structures.” It is striking, indeed, that all of the world’s alphabets share many nontrivial properties, including fine foveal visual features made of nonarbitrary line junctions, typically consisting of about three lines and forming a hierarchical combinatorial code^{1,5}. The generations of scribes that preceded us may have unknowingly been designing near-optimal stimuli for an ancient cortical pathway—the very letters that you are now effortlessly deciphering.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

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