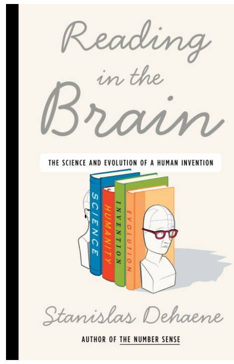


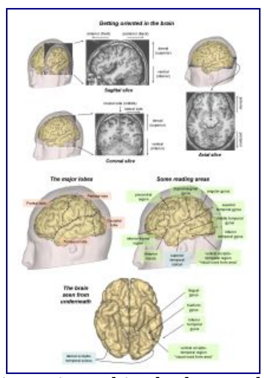
Reading in the Brain by Stanislas Dehaene

A book published by Penguin Viking, November 16th 2009

Overview and color figures

This page includes all of the full-color figures in the book. Click on any of the figures to enlarge it and read its legend. Please refer to the printed version for details.

Introduction: The New Science of Reading

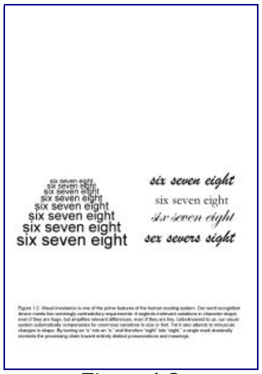


Getting oriented in the human brain

Chapter 1. How do we read?

Written word processing starts in our eyes. Only the center of the retina, called the fovea, has a fine enough resolution to allow for the recognition of small print. Our gaze must therefore move around the page constantly. Whenever our eyes stop, we only recognize one or two words. Each of them is then split up into myriad fragments by retinal neurons and must be put back together before it can be recognized. Our visual system progressively extracts graphemes, syllables, prefixes, suffixes, and word roots. Two major parallel processing routes eventually come into play: the phonological route, which converts letters into speech sounds, and the lexical route, which gives access to a mental dictionary of word meanings.


Figure 1.1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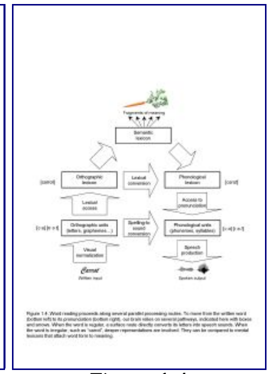
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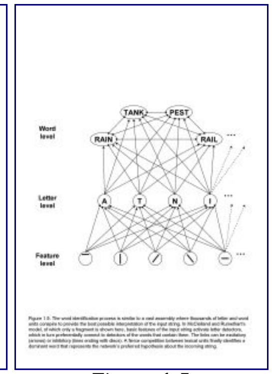
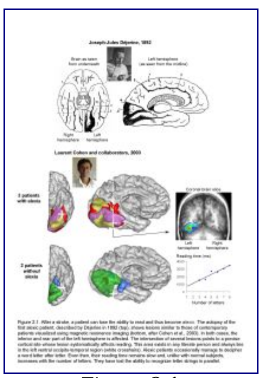


Figure 1.5

Chapter 2. The Brain's Letterbox

In 1892, the French neurologist Joseph-Jules Déjerine discovered that a stroke affecting a small sector of the brain's left visual system led to a complete and selective disruption of reading. Modern brain imaging confirms that this region plays such an essential part in reading that it can aptly be called "the brain's letterbox." Located in the same brain area in readers the world over, it responds automatically to written words. In less than one-fifth of a second, a time span too brief for conscious perception, it extracts the identity of a letter string regardless of superficial changes in letter size, shape, or position. It then transmits this information to two major sets of brain areas, distributed in the temporal and frontal lobes, that respectively encode sound pattern and meaning.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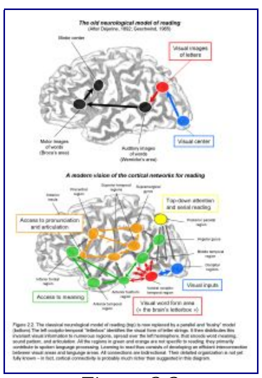
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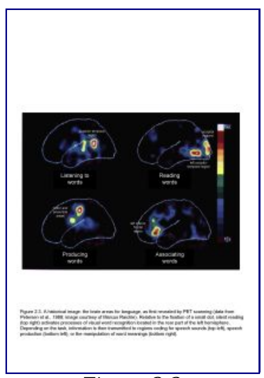
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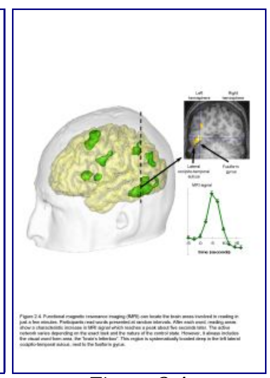
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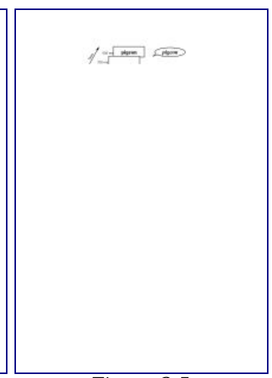
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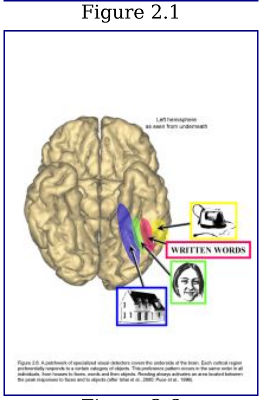
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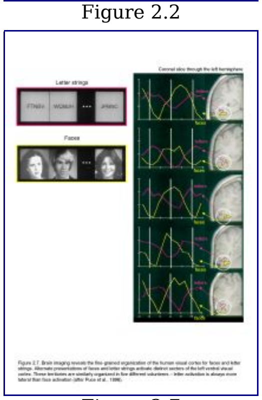
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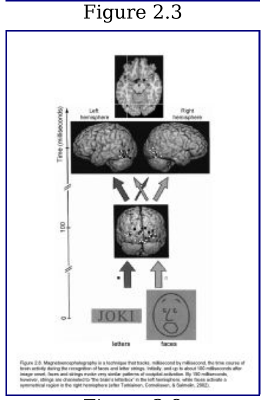
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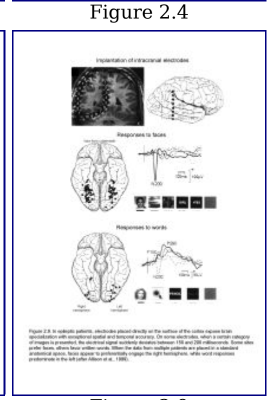
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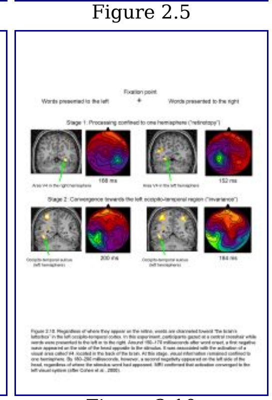
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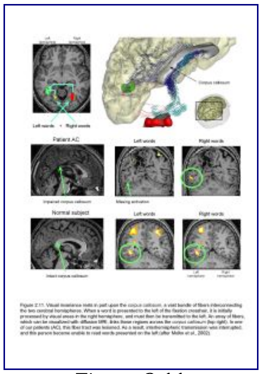
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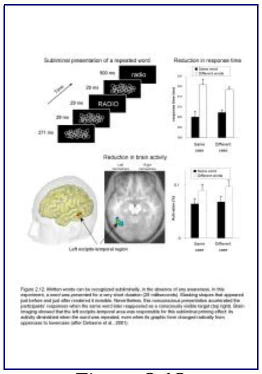
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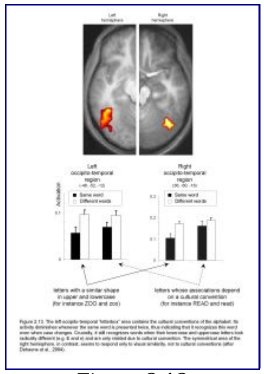
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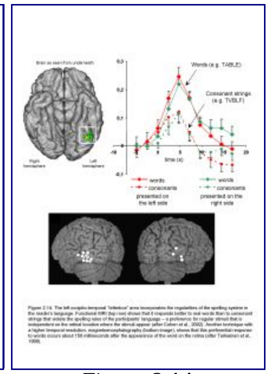
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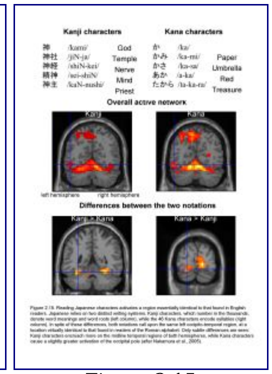
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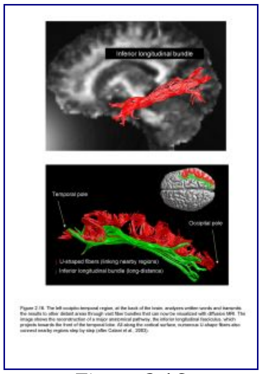
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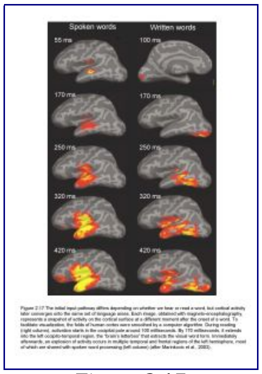
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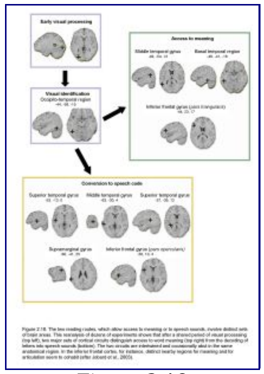
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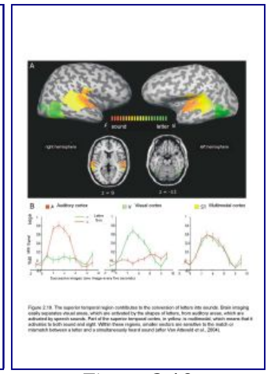
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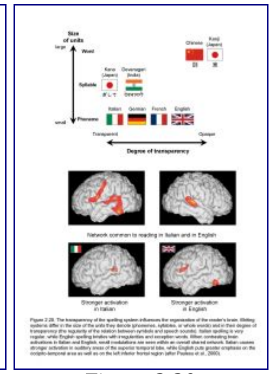
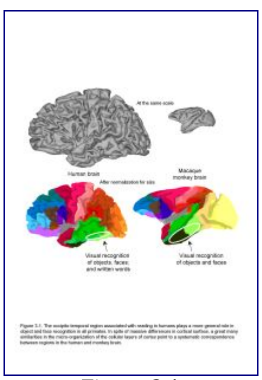


Figure 2.20

Chapter 3. The Reading Ape

Reading rests upon primitive neuronal mechanisms of primate vision that have been preserved over the course of evolution. Animal studies show that the monkey's brain houses a hierarchy of neurons that respond to fragments of visual scenes. Collectively, these neurons contain a stock of elementary shapes whose combinations can encode any visual object. Some macaque monkey neurons even respond to line junctions resembling our letter shapes (e.g., T, Y, and L). Those shapes constitute useful invariants for recognizing objects. According to the "neuronal recycling" hypothesis, when we learn to read, part of this neuronal hierarchy converts to the new task of recognizing letters and words.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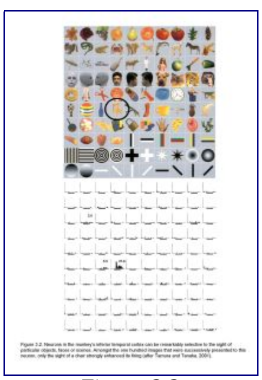
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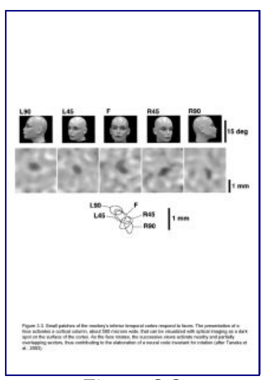
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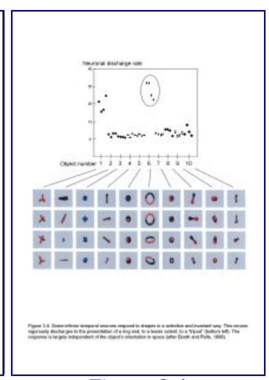
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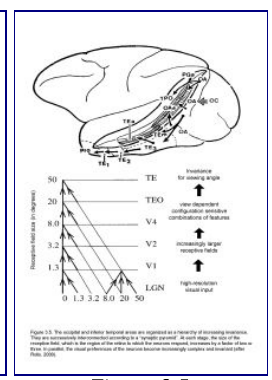
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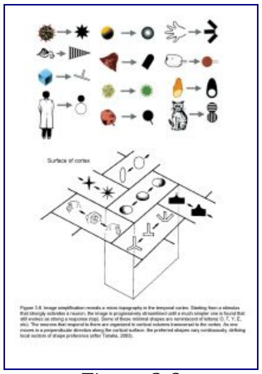
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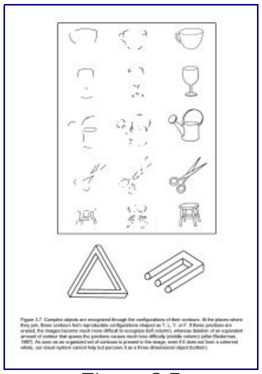
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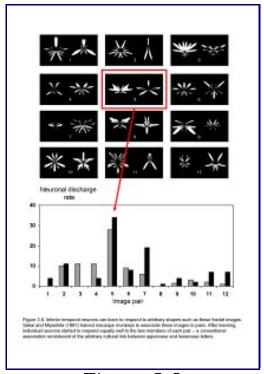
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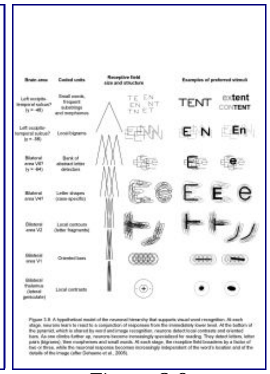
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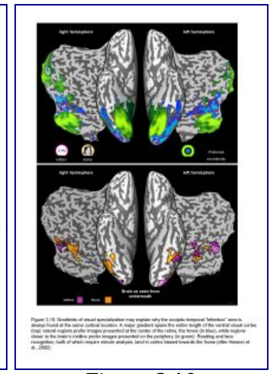
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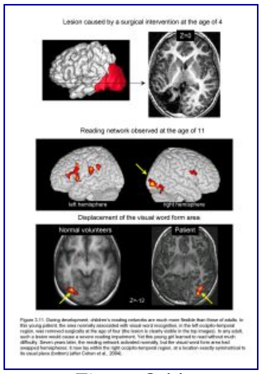


Figure 3.11

Chapter 4. Inventing Reading

The neuronal recycling hypothesis implies that our brain architecture constrains the way we read. Indeed vestiges of these biological constraints can be found in the history of writing systems. In spite of their apparent diversity, all share a great many common features that reflect how visual information is encoded in our cortex. The neuroscience of reading sheds new light on the twisted historical path that finally led to the alphabet as we know it. We can consider it as a massive selection process: over time, scribes developed increasingly efficient notations that fitted the organization of our brains. In brief, our cortex did not specifically evolve for writing. Rather, writing evolved to fit the cortex.


Figure 4.1

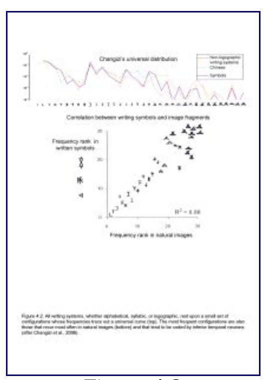


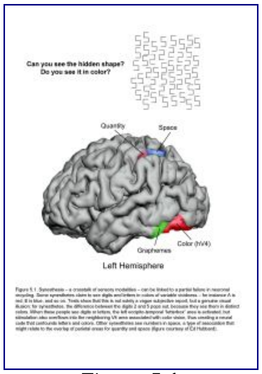
Figure 4.2


Figure 4.3

Chapter 5. Learning to Read

Learning to read consists of connecting two sets of brain regions that are already present in

infancy: the object recognition system and the language circuit. Reading acquisition involves three major phases: the pictorial stage, a brief period where children "photograph" a few words; the phonological stage, where they learn to decode graphemes into phonemes; and the orthographic stage, where word recognition becomes fast and automatic. Brain imaging shows that several brain circuits are altered during this process, notably those of the left occipito-temporal letterbox area. Over several years, the neural activity evoked by written words increases, becomes selective, and converges onto the adult reading network.
These results, although still preliminary, are rich in implications for education. Above all, we now understand why the whole-language method deluded so many psychologists and teachers, even though it does not fit with the architecture of our visual brain.



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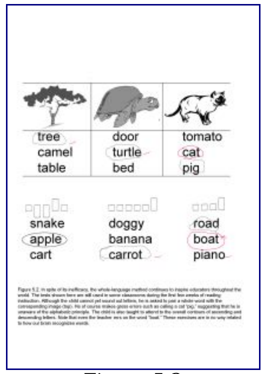

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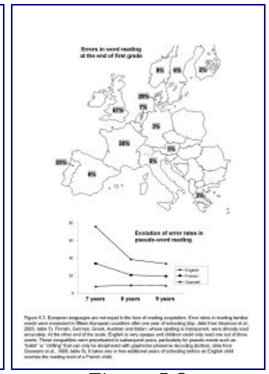
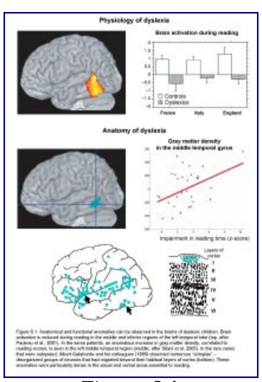


Figure 5.3

Chapter 6. The Dyslexic Brain

Some intelligent and well-rounded children experience disproportionate trouble in learning to read—dyslexia. In most cases, this problem is linked to an impaired ability to process phonemes, and an entire causal chain from gene to dyslexic behavior is now being uncovered. The brains of dyslexic children present a number of characteristic anomalies: the anatomy of the temporal lobe is disorganized, its connectivity is altered, and several regions are insufficiently activated during reading. The disorder is suspected to have a strong genetic component, and four susceptibility genes have been identified, most of which control neuronal migration, a major event in the construction of the brain during pregnancy. Any disturbance that affects this episode can lead to a disorganization of the layers of the cortex.
Do these biological anomalies imply that dyslexia cannot be cured? Not at all—new remedial intervention strategies are bringing fresh hope. Based on intensive computerized training, these techniques improve reading scores and lead to partial normalization of brain activity in dyslexic children.



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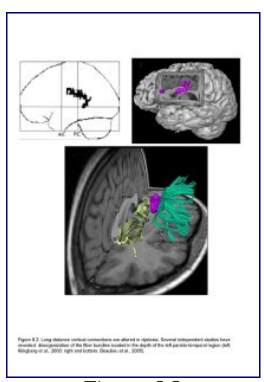
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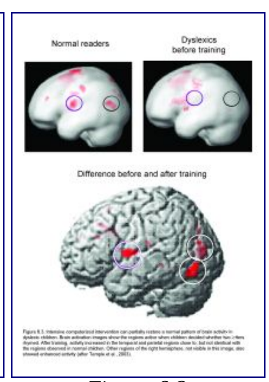
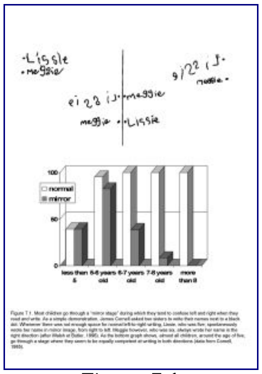


Figure 6.3

Chapter 7. Reading and Symmetry

In everyday language, a dyslexic is someone who confuses left and right and makes mirror errors in reading. Symmetry perception probably plays a significant role in reading, but left-right confusions are not unique to dyslexics. Early in life, virtually all children make mirror errors in reading and writing. Indeed, the ability to generalize across symmetrical views, which facilitates view-invariant object recognition, is one of the essential competences of the visual system. When children learn to read, they must “unlearn” mirror generalization in order to process “b” and “d” as distinct letters. In some children, this unlearning process, which goes against the spontaneous abilities inherited from evolution, seems to present a specific source of impairment.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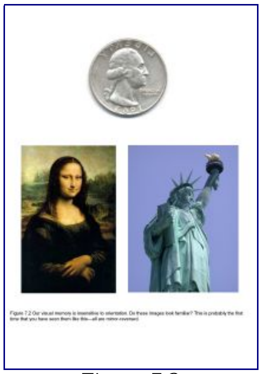
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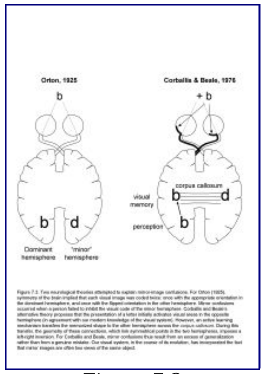
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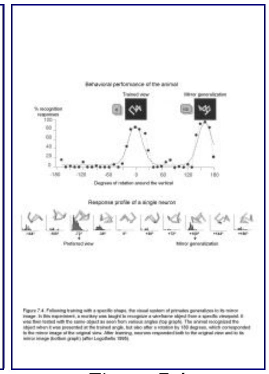
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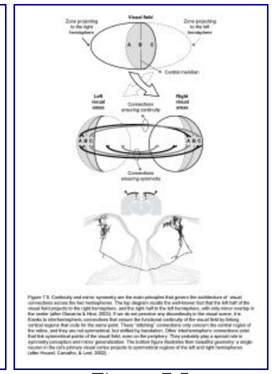
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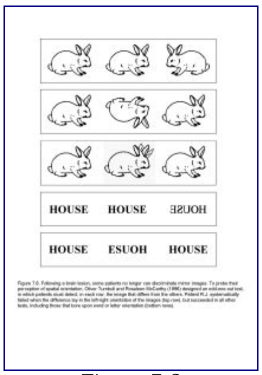
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Figure 7.7

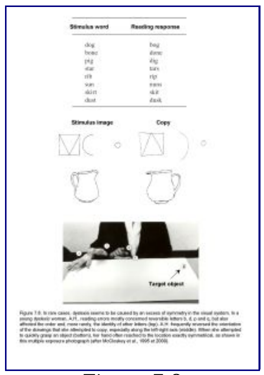
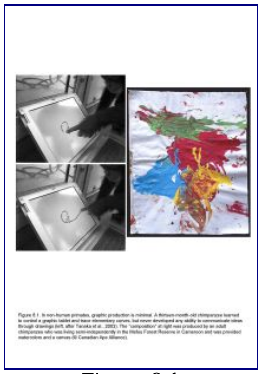


Figure 7.8

Chapter 8. Toward a Culture of Neurons

Reading opens up whole new vistas on the nature of the interactions between cultural learning and the brain. The neuronal recycling model should extend to cultural inventions other than reading. Mathematics, art, and religion may also be construed as constrained devices, adjusted to our primate brains by millennia of cultural evolution. There is, however, a key unresolved question: why are humans the only species to have created a culture and thus conceive of new uses for their brain circuits? I propose that the expansion of a “conscious neuronal workspace,” a vast system of cortical connections, allows for the flexible rearrangement of mental objects for novel purposes.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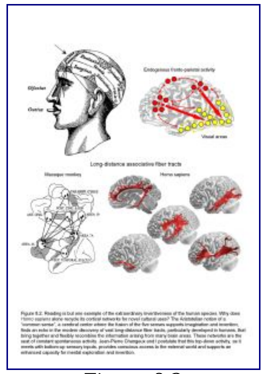
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