REVIEWS/RESENHAS

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Dehaene, Stanislas. *Reading in the Brain.* USA: Penguin Group, 2010.

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The art of reading has fascinated researchers from different fields of interest as it is considered a paramount aspect of human development. Now not only researchers, but lay readers may benefit from a contemporary and well-informed publication on cognitive neuropsychology, *Reading in the brain,* by Stanislas Dehaene. The basic premise of the book lies on the assumption that cerebral plasticity yields an adaptive process of our neuronal circuits to operationalize cultural and educational inventions such as reading and writing, which are characteristic of the society we belong to.

Stanislas Dehaene is a well-established researcher in the field of cognitive neuroscience with a particular interest in language and number processing, and he is the author of several books on the topic, such as "The Number sense". He is a professor of Experimental Cognitive Psychology at the Collège de France, and the director of the Cognitive Neuroimaging Unit in Saclay, France.

Reading in the brain works at different levels; including up-to-date scientific information, and reviews of significant studies in the field of neuroscience and cognitive psychology, expressing them in language that is not too specialized, and also with suggestions for further readings. Dehaene includes useful illustrations, examples, explanations and interesting metaphors that capture complex processes in easier to read language. Unfortunately, the illustrations in this issue are in black and white, although the author sometimes refers to colored parts in them. As a whole, these textual strategies make the book accessible to a wide readership.

Nevertheless, Dehaene does not minimize the complexity of reading, which he accurately depicts as cognitive activity involving several subprocesses, of a vastly parallel nature, which interact as reading takes place in the human brain. The author points out that neuroscience research has offered findings from brain imaging enabling the identification of the brain areas involved in reading, although still controversial. These findings, in turn, have helped to establish a new theory of reading, whose main claim rests on the notion that neuronal networks in the human brain are "recycled for reading". According to Dehaene, this new theory can cause a dramatic change to our understanding of the human brain, its involvement in reading and other complex cognitive activities.

Moreover, he states that neuroscientific data offer contributions to pedagogy and pedagogical actions for reading problems such as dyslexia. For instance, by challenging literacy approaches such as the "whole word" approach, and confirming that the systematic use of the phonics approach benefits the learner to a greater extent. And, in the near future, neuroscientific findings about how the "brain learns to read" could inform literacy teaching.

Dehaene refutes the empiricist view and the social sciences perspective that compare our brain to a *tabula rasa,* which would be shaped by environment, culture and experience. In fact, according to research findings the author argues that brain architecture is similar across human beings regardless of their culture. In response to those views, Dehaene proposes a theory of neurocortical interactions, in other words, the neuronal recycling hypothesis.

Although the author also considers how literacy has affected the brain, he claims that evolution works on a random path, therefore the plasticity view of the brain as being constructed by our previous experiences and environment is seen as too simplistic. Actually, the author states that the period in which human beings have been able to read and have developed reading is not long enough to warrant the argument that our brain has evolved via reading – this is what the author calls the "reading paradox".

In response to this paradox, Dehaene claims that neuroscience findings indicate that the adult brain presents circuits that are specialized in recognition of writing. Yet, the brain has evolved over millions of years, and reading only appeared a few thousand years ago, which leads the author to suggest that the human brain may have specialized cortical mechanisms that are attracted to written input. On one hand, our brains apparently have pre-representations, which are used to help us deal with our environment and with variable situations, and there is flexibility in the brain in this sense. On the other hand, there are constraints, in the sense that the pre-representations are minimally altered to meet new demands – limited to those circuits that are amenable to change.

All in all, the discussions developed about the implementation of reading processes in the brain are well-developed throughout the book. The organization of the book facilitates and guides reading about this complex theme as is divided into an introduction, eight chapters, and a conclusion. It also contains author's notes, the bibliography, the index and figure credits all presented at the end of the book, thus not distracting the audience from their reading. However, not all references are listed in the bibliography, either in the useful general sources or in the detailed references, unfortunately. Each chapter is structured with a brief introduction followed by headings and subheadings that Dehaene uses when posing questions to orient reading. More information on further research is presented, in the tradition of scientific research reports, whereby knowledge acquisition is seen as cyclic and continuous.

Dehaene starts chapter 1, *How do we read?,* explaining some fundamentals of the functioning of reading by discussing the specificities of the organ responsible for receiving visual input – the eye. The author describes how the retina deals with visual information, stressing the role of the fovea that contains high-resolution cells and is located in the center of the retina. Thus, Dehaene emphasizes that eye-movement in reading is characterized by fixations and saccades, which, ultimately, affects reading gaze and time.

The anatomical aspect of reading is subsequently related to the reading processes of decoding and encoding, which are seen as simultaneous processes. The author emphasizes the issue of "invariance" in processing of written input, that is, letter recognition is not affected by varying letter shapes or sizes, apparently; we recognize letter common traits, and these are the "invariants" in letter and in word recognition.

The key to understanding how the human brain deals with invariance may reside in the hierarchical organization of decoding subprocesses of reading in each letter, grapheme, phoneme, in morpheme recognition and the use of affixes in word formation. Dehaene's hypothesis is: "every written word is probably encoded by a hierarchical tree in which letters are grouped into larger size units, which are themselves grouped into syllables and words" (p. 22). According to Dehaene, we naturally focus on morphemes in word recognition processes, i.e. we focus on finding meaning, but we move through levels of representation to get to meaning.

Having said that, Dehaene analyzes the neural behavior in dealing with this hierarchical meaning searching process, and he claims that we have neurons with a specific function as abstract letter detectors. In order for such abstraction process to be carried out, there is a filtering mechanism consisted of a feature detector neurons that differentiates upper case from lower case letters. In this sense, abstract letter detector neurons associate upper case and lower case of a given letter as two possible forms of that letter, thus representing an abstract code that guides the brain towards its corresponding sound and meaning.

He further explains that encodings realized by neurons in the primary visual form area are progressively recoded to be finally related to a mental lexicon, as if the input could find its mental address in a the mental lexicon. In addition, the author discusses two possible routes for word recognition, the phonological route and the direct lexical route, which are subsequently presented in chapter 2, where the author explains that those routes represent the dual-mode model. According to the author, the phonological route refers to the mechanism via which we relate form to sound, letter to sound, grapheme to phoneme, while the direct lexical route refers to the mechanism we have for associating written input to its meaning. Dehaene acknowledges that there is a consensus regarding the dual-mode model, apparently both routes may function simultaneously, working in parallel.

In sum, in chapter 1 Dehaene describes reading by using theoretic advances from cognitive psychology, exploring reading behavior, and bringing forth an analytical view of spelling systems across cultures. Additionally, he posits the important issue of invariance in letter recognition and explains reading processes at the level of decoding, including neuroscience considerations Important information about what we know about reading is presented by the author in a reader friendly manner using metaphors such as "the silent voice", the metaphorical proposal that "every word is a tree", the idea of "competing neurons" to explain parallel processing, which together allows the lay reader, as well as the novice researcher, to deal with abundant information about complex processes, and at the same time "refreshes the memory" of more experienced readers in the topic.

In chapter 2, *The Brain's Letterbox*, Dehaene reviews findings from brain imaging studies, and how they may provide support for the neuronal recycling hypothesis and the importance of what he calls the brain's letterbox. The studies presented in this chapter offer a suitable overview of the contributions of neuroscience to the field of reading, in particular at the level of decoding, using techniques and technological advances that afford visualizations of the cerebral areas involved in reading, ranging from post-mortem to modern methods such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), and positron emission tomography (PET). In this sense, chapter 2 focuses on the role of the occipito-temporal region in the left hemisphere –which the author refers to as the brain's letterbox. The metaphor is very fortunate since it does express the properties of that cortical region, also referred to as the visual form area. Moreover, the concept of this cerebral letterbox guides the second chapter, suggesting a specific property of the left occipito-temporal region.

When comparing old neurobiological models of reading to the modern vision of the cortical networks for reading, Dehaene uses illustrations that nicely summarize the development of findings about the implementation of reading processes in the brain (p. 63). However, as previously mentioned, the figures are in black and white in the book, although the author refers to them as if they had been presented in color in the aforementioned figures. The illustrations are available in http://readinginthebrain.pagesperso-orange.fr/figures.htm, address which, unfortunately is not mentioned in the book. Nevertheless, the author adequately reminds the reader that nowadays we have a more complex representation of the reading process, which is very fast and parallel in nature, different from its sequential representations of the past. However, the role of regions in the occipital lobe, as the primary visual area, has not been challenged because it had just begun to be understood with post-mortem studies. Rather, the role of the left occipito-temporal region is further explored and better understood.

Dehaene reviews findings from brain research from the nineteenth century up to current neuroscience studies, including seminal studies, such as the one conducted by Déjerine (1887) and his patient Mr. C, exemplifying results with the brain's letterbox area hypothesis. Research has shown a relationship between the left occipital temporal lobe and letter recognition, based on findings from examinations of brain-lesioned patients, particularly of those suffering from alexia and pure alexia. The author acknowledges that advances in methods, such as EEG, PET, fMRI and MEG, have enabled in depth examinations of the functioning of the left-occipito-temporal area. Indeed, Dehaene provides the lay reader with simple explanations regarding the methodologies and procedures underlying those technological devices, as well as he leads students and researchers to complementary reading on fundamental literature. Nonetheless, while results concerning the exact regions in the brain that compute cognitive processes are neither conclusive, nor homogenous, extreme caution should be exercised when analyzing brain imaging results not to make broad generalizations, since millimeters in the brain may underline a major difference.

The aspect of invariance is revisited with Dehaene presents EEG, and MEG studies with real-time data that support this problem in letter, grapheme and word recognition that are characteristics of decoding processes in reading. Findings from those studies once more confirmed the hierarchical organization in the occipito-temporal area with neuronal activity from the posterior to the anterior sections of that cortical region with increasing abstraction, which the author interprets as evidence of neuronal adaptation. In reviewing the studies presented in chapter 2, Dehaene argues for cultural adaptation to alphabetical conventions and arbitrariness of the relationship between upper case and lower case letters. He advocates for the possibility of hemispheric specialization, since empirical data indicate that the left hemisphere shows a particular ability to abstract letters regardless of case, shape or size; while the right has not shown the same potential, with the latter responding mostly to image similarities.

Concerning the role of the corpus callosum (the region that links left and right hemispheres), Dehaene brings forth evidence from neuroscience that nervous connections sent from visual regions of the right hemisphere to the left occipito-temporal region travel through the corpus callosum, a process that is compromised when the corpus callosum has a lesion, as empirical data show. Thus, the reader can infer that the corpus callosum is part of the reading pathway. Additionally, other studies confirm the existence of such pathway from left occipito-temporal region to Wernicke's area and Broca's area.

Studies across participants from different nationalities, thus users of language that have alphabetic and non-alphabetic writing systems; and also distinct cultural background characteristics are included by Dehaene. They point to the remarkable conclusion that the role of the left occipito-temporal region is confirmed across participants with distinct first languages. The author discusses the role of the visual form area with participants ranging from western languages with varying degrees of transparency, such as Italian (transparent) or English (opaque), to Chinese and Japanese languages, with variance in terms of transparency and directionality of reading as well. Dehaene briefly considers the reading paradox, for this common role of the letterbox area cannot be explained in evolution theories, since reading is a recent phenomenon in evolutionary terms. The author concludes that there is a consensus about the visual form area, the *letterbox*, which is present in the human brain in roughly the same location in individual across different cultures, from western to eastern ones.

In addition to the role of the visual form area, i.e., the letterbox, brain imaging studies confirming the phonological and the direct lexical routes are analyzed. Amongst them, Dehaene cites studies with words and pseudo-words confirming the dual-mode model with transparent and non-transparent words. As regards the lexical route, studies show that the temporal and the middle temporal regions are involved in semantic processing regardless of the input mode. Areas in the temporal lobe and in the pre-frontal cortex were shown to be involved in sentence processing. In short, brain imaging results support the dual-mode model.

Retaking the paradox, Dehaene argues for the universality of the left occipito-temporal region as the region where people from all cultures recognize words, and he reiterates this universality, in particular for the issue of invariance Also, he agrees that decoding is a vastly parallel process across cultures, with an array of neurons in activation when decoding takes place, and that the two reading routes exist in both western and eastern cultures, with variations in tendency towards the phonological route or the direct lexical route related to the degree of transparency and organization of a given language.

Despite the abovementioned conclusions, Dehaene refrains from solving the paradox just yet, and suggests further considerations. In fact, he proposes revisiting our primate origins and examining other primates' brains by recollecting studies that examined the brain of apes. This examination is carried out in chapter 3, *The Reading Ape*, in which Dehaene defends the argument that the human brain can read due to our brain architecture and neuronal circuitry.

This idea is supported by findings about the brain of apes. An interesting similarity is the correspondence between areas of the monkey's brain and the human brain. The author refers to Brodmann's subdivision of the cortical areas to explain that correspondence. However, Dehaene does not explain the importance of Brodmann's classifications to the field, leaving those less experienced readers at a disadvantage.

Nevertheless, Dehaene draws the reader's attention to many relevant issues, in particular the fact that apes apparently are endowed with a primary visual area like human beings. Having said that; in humans, the occipito-temporal region, as already discussed, is very connected to reading, so much so, that is called the brain's letterbox. In apes, the occipito-temporal region is devoted to the recognition of faces and objects.

Another very relevant aspect is invariance in face recognition exhibited by apes (Tanaka, Tomonga, & Matsuzawa, 2003). Findings from that research showed that monkeys were able to cope with face rotation, and they did so by adjusting their view to a certain angle. The neuronal rationale is based on neuronal specialization, with some neurons being more sensitive to rotation and others being more prone to abstract to an object irrespective of the angle at which it is presented.

This characteristic of primate brains is seen by Dehaene as indicative of our ability to deal with shape, size and position variances in letter and word recognition. Connecting that to human processes, the author revises a study by Rolls (2000) that proposes a hierarchical organization of the occipito-temporal areas which is seen as vital for understanding primate visual systems. Rolls's research is particularly interesting for it is about face-recognition of an epilepsy patient who seemed to have neurons that recognize Hollywood superstar Jennifer Aniston presented in different ways – color photograph, caricature, close-up picture and even her written name. The primate brain ability to deal with variance is therefore understood as the "predecessor of reading".

Dehaene relies on Tanaka et al. (2003) to propose the idea of a neuronal alphabet in the monkey brain, i.e., neurons dedicated to shape fragments. The study used images that were simplified to what the researchers considered to be their basic shapes, and there were neurons that responded to basic shapes, in particular shapes that were simplified to a Y or to a T shape, which Dehaene calls "proto-letters". The author revises other studies leading to the conclusion that the primate brain in fact, holds an "innate shape lexicon". However, he expresses a doubt concerning the nature of the shape lexicon by admitting that in human beings, the lexicon could be learned Additionally, this recognition of basic shapes allows for the combination of a wide variety of shapes primates may encounter, and shapes used in combinations are likely to be those more frequently present in a given environment. Alternatively, shapes may be taught, in which case, they have a chance of being encoded in higher-level neurons in the primate brain.

Considering the possibility that the primate brain learns to recognize the shape of a T, Dehaene suggests that this shape may represent the edge of an object, assuming that same "T" a monkey may use to recognize an object, humans use to symbolize letters. As a matter of fact, these shapes are processed in the occipito-temporal region, the same area that humans use to process letters, thus DDehaene proposes that while humans use the occipito-temporal region to recognize words, apes use that same area to process shapes, ultimately concluding that the human brain did not evolve to read, but our writing systems instead, have stemmed from cerebral characteristics.

Having in mind the assumption proposed by the neuronal recycling hypothesis that brain structure constrains sets of writing systems to be learned, Dehaene proposes two other questions to be addressed in the next four chapters (chapter 4, *Inventing Reading*; chapter 5 – *Learning to Read;* chapter 6 – *The Dyslexic Brain;* and chapter 7 – *Reading and Symmetry)*: Question (1) "*How did humans discover that their visual cortex could be turned into a text comprehension device?";* Question (2) "*How does this recycling process recur in the brain every time a child learns to read?*", while considering three consequences of the neuronal recycling hypothesis. First, the evolution of writing, in the sense that past and present writing systems should carry some common cross-cultural regularity, in agreement with our brain organization constraints. Second, the evolution of human abilities, since learning new abilities, such as reading and writing, may happen at the expense of losing others. And third, the acquisition of reading, on the basis that learning to read depends both on the amount of cortical recycling required and the compatibility of teaching methods and the structure of our cerebral networks.

In chapter 4, *Inventing Reading,* Dehaene discusses more specifically how the neuronal recycling hypothesis may account for brain constraints in the development and acquisition of writing systems. The author briefly reviews the evolution of writing systems citing researches and bringing figures, providing the reader with an overview of the evolvement from cave paintings to the alphabet we know today. Despite the fact that writing systems may vary greatly, Dehaene suggests that they all share many features and proposes the *magic formula* of three strokes per character, a combination that can be easily processed by neurons in the visual area in a pyramidal shape. For instance, writing systems present characters formed of two, three, or four shapes and strokes, and such hierarchical combinations create sounds, syllables, or words. Besides, location and size of characters are irrelevant, but not rotation, which should be restricted to a maximum of forty degrees, a limitation for our visual neurons that is followed across writing systems.

Dehaene starts chapter 5, *Learning to read,* using the terms 'learning' to read and 'acquiring' reading as interchangeable concepts, which may not be a common understanding in the second and foreign language research literature, in which the learning-acquisition dichotomy have different meanings. The purpose of chapter 5 is to advocate for a new perspective of reading mechanisms and their implications for teaching.

According to the neuronal recycling hypothesis, learning to read connects two brain regions already present in infancy: (1) object recognition system; and (2) language circuit, regions that after years of practice are refined, such as the left-occipito-temporal letterbox area, onto the adult reading network. Thus, the prediction is that reading gradually concentrates on the left-occipito-temporal letterbox area, as well as other areas, as the child masters the writing process. A denser discussion is presented based on the three stages for learning to read proposed by Frith (1985), which provides a description of children's learning curve, and followed by pedagogical implications on teaching reading.

In an interesting description, the author accounts for the development of the baby brain considering speech comprehension and invariant visual recognition aspects. Babies are able to perceive linguistic contrasts and the rhythm of their L1 in the utero: activation in the left hemisphere areas, such as the left superior temporal region, the temporal lobe, and the left inferior frontal region (Broca's area) can be seen. And when they are from six to twelve months old, their brains systematically select and classify segments of speech so that they recognize regularities in speech. Two-year-olds learn an average of ten to twenty words a day, and by the time they have their first reading lesson, at the age of five or six, they are phonology 'experts', having a large vocabulary and understanding the basic grammar rules of language, as Dehaene supports.

At the same time, the visual system is organized in a way that the baby is capable of perceiving one object within the visual scene, and follows it as it moves around it. Some features help the baby, such as texture, contours, and internal organization of the object. Besides, the visual system organization also influences the different viewpoints the baby uses to see the object, making inferences about it. It has not been determined yet exactly when recognition of faces, places, and objects that activate brain regions in babies reaches the adult format. For instance, the ability to recognize faces at two months old activate the occipito-temporal cortex used in adults too, which may be enhanced over time as babies recognize faces around them. What is known is that at five or six years of age, the visual recognition process is ready, however still plastic enough to foster for learning of new information, such as letter as this is the time when children go to school to learn how to read.

As regards the first stage of learning to reading (Frith, 1995), the logographic or pictorial stage takes place at five or six years, before formal reading instruction. The visual system recognizes words as faces and objects, and it relies on visual features, such as shape, colour, and letters to identify them. Becoming aware of phonemes happens during the second phase, the phonological stage, in which the child decodes words into letters and connects letters to sounds, that is, the development of grapheme to phoneme. In this phase, the child focuses on isolated letters or on relevant letter groups, and practices linking graphemes to speech sounds to form words. Finally, the third stage corresponds to the orthographic stage, in which the child has a large lexicon of visual units and reading time is determined by word frequency, rather than word length, i.e., rare words are read more slowly whereas more frequent ones are read faster.

Dehaene observes that the first years of formal reading teaching are crucial for children's efficient development and the author emphasises that the key element in learning to read is 'phonemic awareness'. He stresses that it is necessary to explicitly teach children that speech is made of phonemes, and when phonemes are combined, they create words. Dehaene's view is based on the assumption that learning graphemes and phonemes happen simultaneously since these two processes constantly interact in a 'spiral causality', with attention drawn to both speech sounds and understanding of letters in a continuum process. Yet, brain imaging has shown discrepancies between literate and illiterate brains, on the account that learning to read greatly alters the brain architecture. Indeed, Castro-Caldas (1999) reported differences not only in participants' performance but also in the brain structure, for example the corpus callosum – the region that links both hemispheres – is thicker in literate participants, which may indicate a more intense exchange of information between the hemispheres.

Although imaging tools used in research have not allowed scientists, at least not yet, to fully observe the reading progress, the neuronal recycling hypothesis presupposes that the visual system gradually specializes, modifying the brain architecture, as it develops when learning to read. Thus, at the pictorial stage, when words are seen as pictures, there is no brain specialization and both hemispheres contribute to reading. However, as the child becomes more expert, the activation gradually concentrates on the left occipito-temporal letterbox area. Dehaene hypothesises that each reading lesson underpins a neuronal re-organization in the sense that some visual neurons that primarily recognized objects and faces now recognize letters, and a similar gradual development is true for phonemic awareness, which develops to more refined structure. Another speculative finding brought by the neuronal recycling hypothesis, and also extremely controversial in the field, is that the brain would lose some cognitive capacity when we learn to read, on the grounds that neuronal circuits once dedicated to other cognitive functions would be now totally devoted to reading.

When it comes to neuroscience and teaching, Dehaene acknowledges the huge gap that there is between theoretical laboratory knowledge and classroom practice. Dehaene proposes a definition of reading ascertain what reading is not, and suggests that reading is based on processes of automaticity and unconsciousness. The child does not start at that level, though, because she ought to be made explicitly aware of the components involved in reading. The author strongly recommends that in order to set an efficient neuronal hierarchy, in which reading may develop, it is necessary to establish a solid foundation first by recognizing letters and graphemes, and after linking them to speech sounds, so that more elaborate processes may emerge, such as spelling, vocabulary, and meaning, to name a few.

Dyslexia is the theme of chapter 6. According to Dehaene, dyslexic children demonstrate a disproportionate difficulty in learning to read that is not caused because of mental retardation, sensory difficulty, or underprivileged family background. The author criticizes the criteria used as a threshold to define reading impairment since the boundaries to distinguish between good and poor readers are not clear, which hinders the diagnostic process of dyslexic children. It is highlighted that dyslexia is no longer seen as a social or a cultural problem, but a pathology that runs in the family and carries genetic heritability of reading abilities. Dehaene sustains that dyslexia may be caused by both visual and language deficits; however, the question of whether dyslexia refers to the cause or the consequence of learning disability still remains, apart from the extensive research conducted on the topic.

The author posits dyslexia as referring to the reading deficit in single word decoding due to impairment in grapheme-phoneme conversion, considering that most dyslexics suffer from a deficit in phoneme processing. Most up-to-date literature understands dyslexia as impairment in speech processing, rather than a reading problem. Children with dyslexia do not have phonemic awareness and show deficiencies in rhyming or recognizing and combining sounds-letters, blending, segmentation, manipulation, and alliteration, among other deficits.

Pioneer studies on the theme conducted by Morgan, Hinshelwood, and Orton believe dyslexia to be an eye movement problem or an inappropriate use of sentence context – the "congenital word blindness". Nonetheless, research has produced consistent evidence on the origins of dyslexia as an anomaly in the phonological processing of speech sounds, with a smaller number of dyslexic children with spatial attention deficits, and most literature tends to agree with such results. Some studies also show that dyslexic children may have deficits in their visual and auditory processing too, but this finding is still being hotly debated. Reading is complex process that requires both low and high level cognitive resources, resources which may also be involved in other cognitive processes. Hence, it has not been demonstrated yet whether such deficits exist due to dyslexia or they co-occur as coincidental associations with dyslexia.

Dehaene cites several studies on dyslexia, examining children and adults, as well as animal studies conducted with rodents. Among them, he brings forth the investigation conducted by Heikki and colleagues, in Finland, with a large potential population of dyslexics over many years. In general, results show a link between early phonological abilities and the ease to later acquire reading. This is explained because dyslexic children suffer from a 'faulty representation of speech sound', which prevents them from accurately processing spoken words and then pairing these words with visual symbols. Along with that study, Dehaene mentions Paulesus' group, in France, which examined Italian, French, and English dyslexic participants, and found insufficient activation in the left temporal lobe, which appears in MRI images as systematically disorganized.

Having brought the evidence provided by those studies, Dehaene starts discussing the anatomy of a dyslexic brain. Broadly speaking, he sustains that MRI images of dyslexic brains reveal the basic layout of the cortex and its connections to be disorganized. He explains that Paulesus' group used the technique of voxel-based morphometry, via which it is possible to measure the amount of gray matter at any point in the cortex, that is, its thickness and folds of the cortex. And that was carried out by the aforementioned group, which found a disorganized left temporal cortex, as well as to a rarefied gray matter in same places, whereas others were denser than normal. He also found that dyslexics had more gray matter in the left middle temporal gyrus, in proportion to their reading speed deficit. The amount of more gray matter in one place and less in others may be explained by 'ectopias', that is, neurons that were not placed correctly. According to Dehaene's reasoning, much of dyslexia may be explained due to what happens with neurons during pregnancy. Neurons are expected to travel immense distances in the fetal brain to reach their appropriate places, from the germinal zone to different cortex layers, but some travel beyond the proper position and crash, others never achieve their final destination and accumulate in ill-shaped cortical cell layer (dysplasia) or forming miniature folds (microgyri).

Dehaene defends the theory of neuronal recycling hypothesis considering another topic that may also corroborate such understanding: reading and symmetry. According to the author, on one hand, visual circuits display several efficient characteristics for reading, on the other hand, other features hinder the process: generalizations of mirror images, that is, when children see letter such as "b" and "d" as the same object from two different perspectives. In his recycling hypothesis, the "mirror stage" is part of our reading development and it vanishes with time. Dehaene explains that the distinction between right and left begins in the dorsal visual pathway, the brain region responsible for gestures in space, and gradually moves to the ventral visual pathway that accounts for object recognition.

In an appealing analogy, the dissociation between right and left refers to object orientation as "manual worker" and object identity as "collector". For Dehaene, the manual worker acts, compares, and manipulates the image, but it is not capable of distinguishing the object; whereas the collector recognises and labels the image, but it pays little attention to location and orientation in space. His understanding of how the symmetry between right and left disappears is based on the assumption that children first see letters in a limited perspective of two-dimensional curves and not in three-dimensional perspectives that allows letters to rotate in space. Then, images representing bigrams, graphemes and morphemes are restricted to the left hemisphere and only for letters in left-to-right orientation; thus, the expert reader knows the statistics of letters in ordinary writing, but not for mirror writing, which remains inoperative in an unexploited reading system.

From early animal studies conducted by Pavlov and human studies dated back to Samuel Orton, both in the 1920s, to a more contemporary view proposed by Corballis and Beale (1970s), what is sustained in the literature and experiments is that visual maps of occipital region of the left and right hemispheres are organized as mirror images of each other: the right visual field projects the image into the left hemisphere and the left visual field projects the image into the right hemisphere. Dehaene asserts that human memory "suffers" from perceptual priming effect, that is, the visual system in the brain processes an abstraction of the scene, an image that is a translation of the symmetry. That means that although we live in a three-dimensional world, including (1) vertical axis; (2) from front to back reference; and (3) from left-to-right axis, the image is recorded in agreement with two main axes, from front to back, and vertical, both of which were more developed in mobile species like us, and due to the gravity force.

Besides, reading and symmetry may also shed some light on the controversial studies on dyslexia, discussed in chapter 6. Dehaene attempts to elucidate the misunderstanding that dyslexic children would suffer from not only a reading deficit, but also from a deficiency in distinguishing left from right, due to the great number of dyslexics who mix "p" with "q", or "b" with "d". However, the confusion of mirror letters can happen to any children, dyslexic or not, as the visual impairment may occur as the result of a phonological deficit. Indeed, "p" and "q", or "b" and "d" are similar plosive phonemes and difficulties in distinguishing them and projecting mirror images from seven to ten years of age may or may not be characteristics of a dyslexic child.

Final remarks about advances in neuroscience research into reading are presented in Chapter 8, *Toward a culture of neurons,* in a celebratory tone for the accuracy of our understanding of the mapping of reading processes in the brain. And Dehaene finally answers his proposed reading paradox. He states that human beings did not go through a biological evolution towards reading, rather than that, reading evolved to suit our brain. He grounds this assertion on the developments of writing systems presenting similarities across cultures, as discussed in previous chapters of his book. The neuronal recycling hypothesis rests on cortical areas having adapted from initial visual recognition invariant objects to reading. His conclusion is that cultural constructions are restricted by our cerebral structure, and with this assumption, it is possible to investigate neuronal recycling for other cultural expressions besides reading.

He supports his assumption on previous research drawing on diverse fields such as neuroscience, citing Jean-Pierre Changeaux, and structural anthropology referring to Claude Levi-Strauss, who according to Dehaene, initially suggested that behind cultural diversity lays universal mental structures that feature similar restrictions. Furthermore, Dehaene's review includes American philosopher Jerry Fodor, the proponent of the modularity of the mind, and the cognitive scientist and French anthropologist Dan Sperber.

Sperber posits that the brain holds innate modules that are universal and, to a certain extent, Dehaene's perspective conflates with Sperber's in the sense that the human brain exhibits specializations. However, Dehaene contends that Sperber may neglect the role of plasticity of the brain, which Dehaene considers to be fundamental to our cognitive potentiality. For Dehaene, reading does not stem from a specialized visual system, rather than that writing systems have changed our brain functionality in such a way that it has in fact, extended our cognitive potential. Therefore, he claims the modular view does not translate the full range of the cortical features, which present some specializations, but exhibit plasticity as well.

The more varied the complexity of cultural or educational innovations, the more the brain circuitry needs to be re-organized. Plasticity seems to be what gives us our edge since it enables the creation and transmission of cultural objects, which are features that are singular to human beings. In terms of transmission, Dehaene reviews Tomasello's research on acquiring language. According to Dehaene, Tomasello asserts that humans do not simply imitate, they interact, and for that humans do not simply focus on the linguistic input they receive while interacting. Instead they also perceive the intentions of use of a given linguistic input. Studies with children during language acquisition phase showed that they do not simply imitate words, but when children are exposed to new words, they first figure out what the words refer to, only then do they assign meaning to the spoken word. Nevertheless, Dehaene contends that Tomasello's research so far explains how we transmit knowledge, but not how we create new knowledge.

As far as this issue is concerned, Dehaene focuses on brain functions in the pre-frontal cortex that show how connections break through modules! First, he points out architectural changes in the pre-frontal cortex in terms of expansion stemming from changes in neuronal functionality. This leads the discussion to characteristics of the pre-frontal cortex, for although modularity features in a great part of the primate brain, the pre-frontal cortex and associated area exhibit connections across cortical areas, showing less specialization, hence more plasticity.

Yet, assumptions corroborate that higher level cognitive processes take place in the pre-frontal cortex. Resorting to ideas proposed in the tenth century by Avicenna, Dehaene's thinking presents novelty in the sense that the pre-frontal cortex seems to be specialized in memory and mental synthesis, which are ultimately linked to imagination, which, in turn, is linked to our aforementioned ability to invent. These ideas are precursors of current findings from neuroscience: multimodality of neurons – in the presence of a current goal, neurons collect information from multiple sources of input coming from sound, images our tactile information; the activation of information in working memory, and the constancy of brain activity. In other words, the brain is never inactive, not even in resting states as confirmed by neuroscience data.

These findings have led Dehaene to conclude that they relate to human beings ability to integrate information from different sources in different ways – we can synthesize information, we can consciously represent information and reformulate it, unlike any other primate. In reading, Dehaene proposes that being literate implies being able to represent and manipulate phonemes, this expanded phonemic awareness is achieved by explicit instruction on the association of grapheme to phoneme – the teaching of the alphabet.

In the concluding, chapter, entitled *The Future of Reading*, Dehaene reiterates the importance of reading to mankind, to its culture and to its mind. Above all, he posits that plasticity explains how education and culture inventions are not fixed and finite. Summing up his theory, it proposes that existing shape recognition structures within the brain, which seem to be mainly concentrated in the occipito-temporal areas have been recycled to provide the network needed to enable the acquisition and development of writing. The principal opposition to this concept is that the brain structure evolved concurrent with the evolution of writing.

Additionally, the author stresses the neuroscience advances about how reading processes are mapped into the brain may provide important contributions to reading pedagogy. Dehaene stresses that empirical data indicate the value of the explicit teaching children the correspondence between letters and speech sounds, and tries to distance his ideas from ideological debate, assuring the reader that this will enable children to read extensively.

Bearing in mind the perspective of beginning researchers, the experience of *Reading in the brain* allowed us to have an overview of the field and how his neuronal recycling hypothesis fits into neuroscientific research in reading. The assumption that the human brain is a blank slate, and that cultural evolution may influence writing and reading circuit systems in the brain as proposed is refuted by Dehaene's own response-provocative position that "only a stroke of good fortune allowed us to read" (p. 302).

Dehaene's reader-friendly book is an invitation to discover neuroscience achievements regarding our understanding of reading, which extends to the general public, ranging from lay readers interested in scientific and cultural themes, as well as to students and researchers.

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