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Neoliterate adult dyslexia and literacy policies: A neurocognitive research review of a curious unexplored phenomenon

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Abstract

There are about 750 million adult illiterates who in principle could learn fluent reading. However, adult literacy programs have performed poorly. Various social and operational reasons may be responsible. This paper explores the role of some neurocognitive reasons in adult performance.

Automatic readers of a script detect letters and words effortlessly and involuntarily. Adults learning new scripts find it hard to attain this performance. Whether illiterate or educated, adults learning a new script detect letters slowly, may make mistakes, understand little, soon abandon the task, and may also forget what they learned.

When neoliterates glance at a text, they often see a jumble of letters and may process only a few of their features. They must activate reading consciously and sound out each letter. The difficulties are perceptual, and interviews suggest that perceptual distortions may continue for decades. This phenomenon called "neoliterate adult dyslexia" (NAD) has escaped attention, possibly because few educated adults need to learn new scripts, and because the adult literacy failures are often attributed to social reasons. The phenomenon also may have been missed because researchers of perceptual learning use simpler stimuli. Automaticity in reading musical notation and air traffic control may reflect similar age-related learning difficulties.

In the brain, the problem may originate at the early stages of the parietal cortex at the dorsal reading path, which constricts short-term visual memory. The visual areas V1 and perhaps V4 may also be involved. Deficits affect the ventral path that provides parallel processing and direct 'print-to-meaning' reading. Some neuronal groups may have a sensitive period that affects the capacity to collect frequency data and to integrate the appropriate features of letters and words. Then adults do not learn to perceive letter shapes and words as easily as most children do. A lack of data and research makes it difficult to design effective interventions.

The adults' difficulties are not linguistic. Dysfluent readers simply cannot decipher the symbols in sufficient time to get to the meaning of texts, or they do so after considerable conscious visual effort. Therefore language competence seems to have little relationship to the visuospatial tasks described in this document. Language knowledge does help predict likely words when judgements must be made on the basis of just a few letter features, but the relative ease of linguistic identification may lead to reading errors.

The readers' symptoms resonate with descriptions of severe and unremitting developmental dyslexia. Certain perceptual deficits may arise during adolescence and become more severe in adulthood. Some adults may become better readers than others. But learning a script at increasingly later ages seems related to worse outcomes, though no data exist to map this trajectory.

To explore this curious phenomenon, this review brings together a range of insights from of neurocognitive research, notably studies on (a) perceptual learning, including studies on feature integration and face recognition; (b) neurocognitive studies aimed at dyslexic children, (c) studies of adults suffering from brain damage that causes alexia, and (d) performance of adult literacy programs. Implications and potential remedies are also presented. The author posits the hypothesis that *perhaps all people become dyslexics for new alphabets at about age 19*, and that ability to read new alphabets fluently decreases with age.

Neoliterate adult dyslexia (NAD) may partly account for the difficulties of adult literacy programs. Thus it seems to impact about 750 million adult illiterates. For this reason, the paper calls for urgent research into this phenomenon.

Keywords: Adult literacy, neurocognitive research, perceptual learning, early-grade reading, dyslexia, alexia, feature detection, implicit memory, neoliterate adult dyslexia (NAD)

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Chapter 1: Background – A curious unexplored phenomenon

September 8 is International Literacy Day, celebrated in many international agencies worldwide. It presents an opportunity to reflect on the spectacular expansion of literacy across the world. Since about 1990, the United Nations agencies and other donors have consistently focused on the importance of education and financed the expansion of primary schooling in low-income countries. As a result, global adult literacy has risen from 56% in the 1950s to 86% in 2015 (UNESCO, 2016). But this growth reflects the impact of children's schooling; it disguises the existence of some 745 million adult illiterates worldwide who are mostly women that have never been to school, and others who may have dropped out of school before learning to read fluently.

Developing functional, usable literacy to adults is target 4.6 of the United Nations' Sustainable Development Goals of the United Nations, which continue to be a world priority. The goal by 2030 is to ensure that all youth, and a substantial proportion of adults, achieve literacy and numeracy[1].

To help adults become literate, donors and governments have financed many adult literacy programs since the 1940s and the 'Education for All' global initiative that ended in 2015 also included an adult literacy goals. But unlike the relative success of children's programs, adult literacy outcomes are virtually non-existent. Evaluations by organizations such as the World Bank, the European Union[2], and the UNESCO Institute of Lifelong Learning, document high adult dropout rates and a continued failure to learn. Those adults who graduate from literacy courses at best read haltingly, letter by letter, and a few months after program completion, they may forget letter sounds (Romain and Armstrong, 1987; Abadzi, 2003).

The failures are often explained away by common-sense beliefs. It is assumed that poor adults have hard lives and little time for study. It is said that they may see no reason for learning, given their social contexts or they may have nothing to read (UNESCO UIL, 2016). Governments and donors, in turn, see no use in financing failing programs, and low investment leads to a downward spiral in effectiveness, forcing the few remaining programs to use volunteer teachers and offer courses that may be only a few weeks in duration and therefore tend to be ineffective.

But adult illiteracy is not going away. Many illiterates are older, but a generation of schooled illiterates is in the making. Schools in poor countries often teach using languages and methods that require parental support and/or offer few books for reading practice. In some countries, civil wars and natural disasters force children out of schools. The number of adult illiterates

[1] The Indicator 4.6.1 is defined by the proportion of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex. This is measured as the literacy rate (the share of the population with at least functional literacy) for youth and adults, differentiated by sex. Such measures of 'literacy' typically also encompass basic arithmetic skills (https://sdg-tracker.org/quality-education).

[2] European Literacy Policy Network. 2016. European Declaration of the Right To Literacy, March 2016.

worldwide may therefore increase in the future. To escape a life of destitution, neoiliterates must be reached and effectively helped to become fluent readers.

As an education specialist at the World Bank, I developed, supervised, and evaluated adult literacy projects in poor countries. Around 1992, I visited and videotaped participants of literacy classes in Bangladesh. After 9-month courses, most could not read at all, and the best could only read effortfully, letter by letter. Many had already forgotten the letters learned a year earlier. By contrast, children of reasonably functioning schools learned the syllabic Bangla alphabet in a few months and did not easily forget. Similarly a few poor women, who had learned reading in childhood, read effortlessly and did not forget reading, despite a lack of daily exposure. It became easy to distinguish the childhood literates from the halting adults (Abadzi, 2003a; 2003b).

However, unschooled illiterates were not the only poor literacy performers. Staff of international organizations, some of whom had spent decades in cities like Dhaka or Bangkok and who spoke Bangla or Thai very well, reluctantly confided that they read haltingly, letter-by-letter. Despite superior education and a brain configured for literacy, they had the same difficulties as the unschooled. They seemed to have acquired dyslexia in adulthood.

The symptoms, issues, and supportive research surrounding adult dyslexia were presented in various publications and conferences over a period of 20 years (Abadzi 1994, 1996, 2003, 2006, 2012). However, interest has been negligible. Some academics and donor staff found the concept of dyslexia for normal adults implausible or ludicrous. They tended to attribute the difficulties of illiterates to social disadvantage, and the difficulties of educated adults to poor command of language or low personal motivation. As a result of this neglect, the phenomenon has not been studied, and no quantitative data have been collected. Over the intervening years, however, much neurocognitive research has been published on visual perception, perceptual learning, statistical learning and dyslexia. The influx of refugees in Europe has also led to the introduction of new adult literacy programs have garnered some performance evidence. These initiatives provide some further insights into the nature of the problem. This article updates earlier reviews, in the hope of raising interest in this phenomenon.

Chapter 2: Hypothesis

The neoliterate adult hypothesis (NAD)

This article, as others I have written before it, posits the hypothesis that perhaps all people become dyslexics for new alphabets at about age 19, and the difficulty further increases with age. Neoliterate adult dyslexia (NAD) may partly account for the difficulties of the unschooled illiterates as well. (See section below on the neuroscience of illiteracy.)

The symptoms described above resonate with descriptions of severe and unremitting developmental dyslexia (e.g. Sigurdardottir, Danielsdottir, Gudmundsdottir, et al. 2017). Certain perceptual deficits may arise during adolescence that become more severe in adulthood. Surely the abilities relevant to reading-related tasks have a distribution, with some people better than others. Learning a script at increasingly later ages seems related to worse outcomes, though no data exist to map this trajectory.

The difficulties are not linguistic. Language competence seems to have little relationship to the visuospatial tasks described in this document. Dysfluent readers cannot decipher the symbols in sufficient time to get to the meaning of texts, or they do so after considerable conscious visual effort. When beginner learners try to learn a language while trying to decipher a script, the process is obviously hard and slow. This is one reason why Arabic, Hebrew, or Chinese take many years of study. But native speakers have the same difficulties. Knowledge and retrieval speed help predict likely words when judgements must be made on the basis of just a few letter features, but it may also lead to errors.

This document presents plausible ways in this can be happening and offers some tentative hypotheses on where difficulties could originate. An extensive research review attempts to integrate studies on (a) perceptual learning, including studies on feature integration and face recognition; (b) neurocognitive studies aimed at dyslexic children, and (c) studies of adults suffering from brain damage that causes alexia. Feature integration and perceptual learning are of particular interest. Since research has not been done on neoliterate adult dyslexia, the studies used are mainly peripheral. The problem is like a prism, whose issues can be explored from multiple facets.

Chapter 3: Observations by an 'illiterate' reading specialist

Imagine that you are a German diplomat, moving to your new post in Kathmandu, Bangkok, Pnom Penh, Aman, or Addis Abeba. You have studied the language and script intensely. At your post, you practice speaking and you become quite fluent, so you expect progress in reading as well. But in stark contrast to reading the Roman script in a foreign language, you become stuck. Letters just do not form words. Deciphering a paragraph of known vocabulary may take 10 minutes or more and is mentally exhausting. Television messages disappear before you can decode them. Street signs are everywhere, providing constant practice opportunities, but you may need to stop and spend minutes deciphering each street sign or name director at a ministry entrance. You are a functional illiterate, lost in an urban sea of letters! In meetings, national staff hear you speak fluently and hand you documents that you may find you cannot read. Emails and collaboration on documents become impossible in the relevant language. And since you cannot read extensive text, you cannot easily improve your academic language. You may feel that you just did not try hard enough to become proficient at reading this new script.

I experience this phenomenon every day. In 27 years of work at the World Bank, I learned about 10 languages for work in countries such as Cambodia, Nepal, Bangladesh, and the Arab world.[3] Despite attaining a high level of oral proficiency in most languages, I read haltingly in all the scripts that I learned after the age of 18. World Bank missions to countries using these scripts usually lasted 1-3 weeks, but my speed quickly regressed after a trip. Under the best circumstances of practice and engagement I could read the Devanagari script in Hindi and Nepali at 60 words per minute around age 50. At age 67, after about 6 years of significant reading and advanced language self-study, I could only read Arabic at 30 words per minute and improved only marginally. This speed is around 10% of educated native-readers' speed.

Since 1992, I have interviewed and given informal reading tests to dozens of educated people who, as adults, learned Lao, Hindi, Hebrew, Arabic, Amharic, Tibetan, Bengali, Japanese, Thai, Russian, Armenian, Farsi, Greek and other languages with scripts different from those studied as children (Abadzi, 1996). Of particular interest were advanced and fluent speakers who should easily understand written text. However, *I never encountered anyone who had learned a script past age 19 and claimed completely effortless reading.*

For example, interviews were held in 2016-18 with 10 Greeks who went to Israel for university studies at age 18 and learned Hebrew reading at that time. They had read Hebrew overall for far more than the 100 hours needed for adaptation by dyslexic students of English-speaking countries. Those who studied and stayed in the country read fluently, but said they avoided

[3] The author is a Greek cognitive psychologist and polyglot of 19 languages, performed at least at intermediary level. Languages with scripts learned in adulthood include Russian at age 18, Hebrew at 19, Hindi at 23, Sinhalese at 28, Japanese kanas at 35, Arabic at 37, Bengali at 42, Khmer at 59 years.

reading for pleasure or outside work hours. They also reported difficulties in scanning text 40 years later. By contrast, average 5th graders in the US can scan text efficiently (Potocki, Ros, Vibert, et al., 2018). Those who returned to Greece lost reading fluency and reverted to laborious decoding of less than 60 words per minute, despite frequent travel and a continued high level of oral fluency. Interviews and tests were also given to two individuals who had learned Hebrew reading as children and who read fluently despite a lack of language knowledge. The difference between these two performance levels was striking.

كفايات كفايات

Arabic print appears different than handwriting. Adult learners must make conscious decisions for various letters

Interviews and personal experiences suggest that acquisition speed slows down in mid-adolescence.[4] Capacity for fluent and effortless reading seems to wane significantly by age 19. Most people interviewed over time read slowly, around 10-20 words per minute. Aside from a few high-frequency words, they only see jumbles of letters. They cannot read involuntarily, as automatic readers do. They must activate conscious pronunciation of the letters in their heads. Thus they cannot read ahead and they cannot speak or listen at the same time, because they must read sub-vocally. Informal 'Stroop tests' fail, and words appearing suddenly, such as titles on TV or the internet, are not recognized. One Greek physician who migrated to Israel at around age 26 reported "seeing a wall before her" when trying to read Hebrew.

A quick glimpse at a text results in lost features and/or connections to the wrong sound. The adults may not perceive a sufficient number of features to identify it and to distinguish it from others. A reader must focus on each letter, think consciously, correct errors. By the time this is accomplished for 2-3 words, the content held in working memory has been wiped out. For example, I outlined an Arabic language curriculum with a set of activities developed by a collaborator. Reading the output at 30 words per minute took hours, and when I demonstrated it to others on the computer, I could not read the display.

Slow and effortful decoding fills working memory with letters and limits comprehension.[5] Conscious searches burden the central executive of the working memory, causing fatigue and

[4] A Lebanese informant reported that she learned Arabic reading at age 13 in the United States, whereas her older brother had gone to an Arabic primary school at 7. He was reportedly reading film subtitles much faster than her. Similar anecdotal concerns have been raised about adolescents who learn to read at 15.

[5] The working memory is a temporary storage of information that contains what is in your mind right now. It consists of an auditory phonological store (called short-term memory), a visuospatial sketchpad for images, and a central executive that hosts prior information recalled from long-term memory along with new information coming in from the outside world (Baddeley, 2003; newer models also exist). The visuospatial sketchpad of working memory determines the eye movements (saccades) in reading *(Van der Stigchel & Hollingworth, 2018)*. Afflicted individuals can accurately distinguish the object, as demonstrated by the ability to draw a picture of it or categorize accurately, yet they are unable to identify the object, its features or its functions.

loss of patience.[6] Neoliterates often give up after 2-3 lines of text, so voluminous practice becomes impossible. Avoidance in turn reduces practice opportunities.

Speed drops significantly when they stop reading for a few days. The phenomenon is perpetual and results in disappointment and avoidance.

Remarkably, many educated neoliterates were reluctant to talk about their reading difficulties. They cannot easily describe them precisely, and they attribute failure to insufficient practice. Many also feel embarrassed that they perform so poorly, after sometimes decades of practice. This was the case with two Sanskrit scholars and, similarly, an American professor of Bengali was befuddled by his difficulties after 20 years of engagement. A Dutch educator who has taught illiterates and who has extensively studied the Amharic script, found that she was making the same mistakes she saw in her students. Subsequently she forgot the shape-sound combinations.

The prevalence of illiterate reading specialists is noteworthy. Donors such as USAID and DFID have invested heavily in primary education, and engaged many reading specialists to design instruction in Arabic and other Asian languages. It was found, however, that unless these specialists were native readers, nearly all remained illiterate when it came to the written, as opposed to the spoken word. People whose careers involve engagement with new languages may learn some oral language but not even attempt to learn reading in the new script.

Some cases, such as the visually complex Khmer script, starkly demonstrate some little-understood perceptual differences: that, with sufficient practice children can learn the multiple and complex shapes, but adults find it hard even to tell the letters apart.

Given a lack of quantitative data, below are some qualitative details, arising from interviews and personal, introspective observations (Adams, 2000).

Perennially slow and inaccurate reading: Beginning readers who progress may read letter by letter fast enough to coincide with a relatively normal rate of pronouncing a word. In time, the letters fall into place, and readers get feedback and complete the pronunciation. But neoliterates may read too slowly for regular speech, so a delay results. The prediction can be completely inaccurate. For example, the Russian никогда vs. иногда may reverse the initial letters that are pronounced differently than in the Latin script.

Difficulty remembering letter shapes and sound correspondences for the long term: Adults may learn alphabets and use them for decoding, but when the engagement ends they may forget the shapes and values. Adult reading illiterates seem to forget sound-letter correspondences within a few weeks.

[6] Prolonged cognitive load is associated with reductions in "rest and digest" parasympathetic activity of the body and increases in "fight or flight" sympathetic activity (Mizuno, Tanaka, Yamaguti et al., 2011). Thus, people feel motivated to stop tedious mental activities.

Systematic neglect of certain letters. In Arabic, I notice dots inconsistently, particularly inside dense areas of information. Incorrect priming from meaning results in neglect of features that should correctly identify a word, and the error may not be noticed until a sentence is incomprehensible and requires a second pass. For example, the Arabic word هدنة (hudna – truce) may be misread as هدية (hadiya – gift). The latter is much more common, so it was retrieved faster than the less common initial mu sound of هدنة. The N in this case lost its dot above. Focusing on a letter that has a dot below it increases the likelihood of neglecting a letter that has 1-2 dots above it. I often skip the initial ya of Arabic words, while trying to focus in the middle of the word to make some sense. So, letter neighborhoods and locations matter, along with independent letter identification. Only a few letters can be read on the fly before making a mistake.

Feature integration difficulties and ambiguities. Personal observations suggest deficits in deciding which features unite to make letters or syllables. Features somehow stay loose and do not get "glued" together. Arabic has obligatorily connected and disconnected shapes, with dots above and below the letters that should be 'wired' to the connected shapes. Examples of slowly and incorrectly decoded words are ينتشر vs. ينتثر (yantathiru vs. yantashiru - disseminates vs. excites). The letters ج ح خ are also difficult. Shapes and dots are perceived as disconnected features rather than integrated shapes. An example is the Hindi words rawana (move) and khana (eat) रवाना vs. खाना that may not be distinguishable. It is similarly always difficult to discriminate between a circular and an elliptical shape: مصر vs. ممر (masr vs. mamar, Egypt, passage). A brief glance at the word هذا (this) changes to the word مذا(what) by ommitting a single feature.

Syllabic scripts are sometimes difficult to decode in series because the syllables force a sense of order. For example, the word Hindi हिंदी can be viewed as two large chunks punctuated by a dot, so it can only be read in that order. The word instantly gets identified.

The following Devanagari characters must be discriminated along some dimensions, and sounds must be reliably connected to the correct shapes.

इ ई ड ह् द्

Recognition of some letters faster than others, particularly those that have distinct shapes (von Restorff, 1933). The letters recognized faster may be pronounced before others, so words are decoded in a scrambled order. Perhaps letters with many features similar to others that require comparison are detected more slowly than letters that share few features with others (e.g., Devanagari ष, क्ष – sh, ksh). Ironically, language proficiency multiplies errors, because word prediction may come faster than the recognition of sufficient letter features. For example, in Arabic, السرعة sura'a – speed, reads as saa.

Reliance on unusual letter shapes. Unusual characterstics at a certain location facilitate distinction. Rare characters or repetitions may help readers identify a word quickly without detecting the rest of its features. For example, in Bengali "Bangladesh" বাংলাদেশ has "ng" that looks like a semi-colon early on, and that shape stands out. In Arabic, مؤسسة (muasasa - foundation) stands out because of the unusual hamzated 'waw' early on. أساسى (asasi, essential) or سياسي (siyasi, political) stand out a bit because of the repetition of shin, separated by a break (alif). It is possible to scan text for a certain word by using limited features; e.g. by thinking of a letter in that word that stands out in a certain position,for example a final shin in Arabic.

Exaggerated word length effect: People in general read longer words more slowly, and children do so in the first 2-3 years. But in adults this tendency seems exaggerated. Readers report reading 3-letter words quickly, but resorting to a letter-by-letter mode in longer words, for example, Баяндамашылар – (speakers) in Kazakh. A reader who learned the Cyrillic alphabet in adulthood recognizes some letters from childhood but must still break the word in 2or 3 parts. Readers may neglect the middle letters, relying on predictions that are often wrong.

Increased practice in one script may speed up others: In efforts to speed up, I read Arabic intensely in 2017-18. After perhaps 50 hours of practice without notable changes, I suddenly improved by about 5 words per minute. The speed declined after inactivity of a few days. However, Arabic helped me to read Devanagari faster. In Hindi and Sinhalese, I noted a tendency to focus on features distinguishing various letters (perhaps due to interleaved training on an unrelated task, (see Szpiro, Wright, & Carrasco, 2014).

Extensive practice slowly resulted in **habituation to smaller size and denser space**. A 12-size Arabic font was impossible to read in early 2016 but became quite legible by the end of 2017. Sinhalese, which has several complex and broad letters separated by millimeters of space, became more legible without extra practice in that language. After much practice, adults may learn to remember the overall shape of common words and skip the dense internal details.

Occasional and inconsistent activation of the print-to-meaning pathway: In Devanagari, which I learned at age 23 and used extensively in my forties, automatic recognition may be activated if I look at a word for 3 to 4 seconds. In 1996, at age 45, I once recognized instantly the word उद्योग (industry). I had expected generalized improvements, but this happened only once. More practice merely increased in the speed of mainly conscious discrimination among letters.

Perennially slower identification of letters representative of non-native sounds: One little-known feature relevant to foreign adult readers is the perennially slower identification of letters representing novel sounds. This was researched in Arabic with children and fluent adults (Ibrahim, Eviatar & Aharon-Peretz, 2007 (Eviatar & Ibrahim, 2014, p. 80). I experience this in Hindi as well as in Arabic with certain letters (ड ट ढ and ط ظ ض).

Difficulties in calligraphic reading: Educated neoliterates can have particular difficulty reading calligraphic signs. Slants, changes in the ratios of letter parts would not confuse children but *letters deviating from prototypical shapes* often seem like different letters. Thus, handwriting, particularly casual scribbling, may remain perpetually undecipherable. Neoliterates even report trouble reading their own handwriting, which is often awkward and deviates from the prototypical letters they studied.

Awkward handwriting: Handwriting seems to have a slightly different age-related decline (see items in the following sections), [7] but observations resonate with dyslexia research on handwriting (Kandel, Lassus-Sangosse, Grosjacques, & Perret, 2017). Informants who learned a script in their 20s reported the ability to write fluently, but the inability to read back what they had written. Some alexics suffer from this phenomenon.

The above observations reflect individual differences to some extent. They may also reflect the biases of people who are literate in the Greek and Latin scripts. Automaticity in prior scripts streamlines certain neuronal pathways to recognize those combinations and could inhibit subsequent attempts to rearrange them in adulthood. [8] For example, childhood readers of Chinese learning Bengali might distinguish different features than Armenians. Thus error patterns may vary because of the readers' native scripts. But such a phenomenon also reinforces the neuroplasticity challenges for adults. In several countries children learn multiple scripts simultaneously and do not appear to suffer from long-term interference.

[7] At age 20, I acquired a nice handwriting in Hebrew as well as a fairly accurate recall of orthography. Around age 40, I wrote extensively in Hindi, but my handwriting perpetually resembles that of a first grader. Around age 45, I started to write in Arabic, but 20 years later my writing remains barely legible, and spelling recall is poor. The writing difficulties of little-educated adults had been noted in the antiquity. One Greek text described a woman as writing slowly, βραδέως γράφουσα (Cribiore, 1996, p. 6).

[8] For example, the Arabic لعا [la'a] may be seen as a head with two raised arms. People may create features to subserve the representation and categorization of objects (Schyns, Goldstone & Thibaut, 1998). "The committee" اللجنة starts with three straight lines that somehow seem easy to ignore.

Chapter 4: The basic neuroscience of reading

What must your brain do if you want to encode and retain the shapes and sounds of letters in Japanese, Sinhalese, Arabic and Hindi? For example こんにちは, ようこそ (Japanese konnichiwa, youkoso) Namaste नमस्ते , සුබ පැතුම් (suba paetum – Sinhalese), මම ඔහුට ස්තුති කළා . The shapes must be encoded, but letters must also be differentiated from others. For example, a learner must differentiate the Sinhalese ma ම from o ඔ. And these distinctions must be made instantly, effortlessly, and accurately. If you slowly spell out ko-n-ni-chi-wa or if you confuse which separated letters make syllables (e.g. බො - bo in Sinhalese) you cannot read more than a few words of text.

A large number of neuro-imaging studies have explored the brain regions involved with reading in normal and dyslexic children and adults. Findings show that specialized brain regions work together to form the reading network. The extent to which these sensory-specific parts of the brain are able to connect as a network, not necessarily anatomically, but functionally, during a learner's development predicts their reading proficiency. This developmental shift integrates previously segregated parts of the brain, suggesting that changes in reading skill are associated with the nature and degree of these changes to the neural pathways within the reading network. As children learn how to read, the brain rewires itself so that it goes from having one area working on visual matters and another working on auditory matters to the two areas working together as a cohesive unit (Smith, Booth, & McNorgan, 2018). In principle, it should be possible to devise teaching methods that encourage more interactive operation of these areas.

To clarify further discussions, below are essentials of reading neuroscience, derived from children's studies.

The ventral 'what' stream and a dorsal 'where' stream

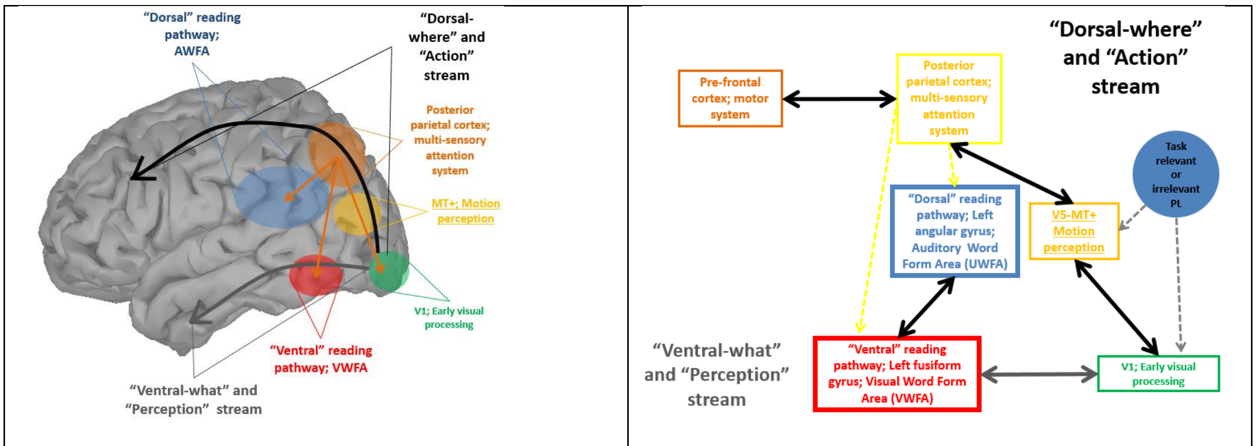
The journey of reading starts in the eye receptors. From the moment light hits our eyes, the visual input is depicted and transported through a myriad of steps and networks. From the eye receptors, a signal traverses the superior colliculi and pulvinar nuclei to the occipital lobe, the V1 area, then travels through paths that recognize shapes toward the parietal lobe, which connects letters to sounds, then finds meaning in the medial temporal lobe. In experienced readers, these functions are recursive and happen in milliseconds. Practice connects the various parts and synchronizes electrochemical signals. [9]

To interpret what we see, our brain needs color, contrast and motion information about our surroundings. In the V1 area, the neurons are arranged in a specific way that allows the visual

[9] Literacy acquisition improves early visual processing and reorganizes the ventral occipito-temporal pathway: responses to written characters are increased in the left occipito-temporal sulcus, whereas responses to faces shift towards the right hemisphere (Dehaene, Morais, & Kolinsky, 2015). Diffusion tensor imaging enables researchers to see the bundles of neurons that move from the visual cortex to the visual word form area.

system to calculate where objects are in space. They are organized ‘retino-topically’, that is, neighboring areas in the retina correspond to neighboring areas in V1. Human neurons sensitive to the same orientation are located in orientation columns, so all neurons only respond to a horizontal stimulus, but not to diagonal or vertical ones (Roth, Heeger, & Merriam, 2018).

As visual information exits the occipital lobe, it follows two main pathways, or "streams". The *ventral stream* (also known as the "what pathway") is involved with object and visual identification and recognition. The *dorsal stream* (or, "where pathway" or “how”) helps process the object's spatial location relative to the viewer and with speech repetition (Cohen & Dehaene, 2009). It is involved in spatial awareness and guidance of actions (e.g., reaching). It contains a detailed map of the visual field, and is also good at detecting and analyzing movements. Reading is probably achieved through a collaboration of the two components of the cerebral visual system.



Figures 1-2. Pathways followed by electrochemical signals in the brain when people read (Gori & Facoetti, 2013; reprinted with permission)

The **dorsal pathway** or stream stretches from the primary visual cortex (V1) in the occipital lobe forward into the parietal lobe.[10] It includes the left angular gyrus that links sounds and shapes (Gori et al., 2013). It is interconnected with the parallel ventral stream (the "what" stream) which runs downward from V1 into the temporal lobe.[11]

The **ventral pathway** or stream identifies complex multipart objects.[12] Words are encoded through a posterior to-anterior hierarchy of neurons tuned to increasingly larger and more complex word fragments, such as visual features, single letters, bigrams, quadrigrams, and possibly whole words. Regions in the ventral pathway underpin direct print-to-meaning processes. From left posterior to anterior occipitotemporal cortex there is an increasingly graded

[10] The parietal cortex is involved in spatial attention and binds features into larger shapes when the features are shown simultaneously at different locations (Shafritz, Gore, & Marois, 2008).

[11] https://en.wikipedia.org/wiki/Two-streams_hypothesis

[12] This is posited as the local combination detector model [e.g. Dehaene, Cohen, Sigman, & Vinckier, 2005). Vision for perception may follow different paths than vision for action, appropriate for avoiding a predator (Schenk, Franz & Bruno, 2011).

response to the word-likeness of written stimuli, with the mid-fusiform/inferior temporal gyrus responding more strongly to words and pseudo-words than to stimuli containing frequent bigrams, followed by consonant strings, then false fonts (Vinckier, Dehaene, et al., 2007). In normal expert readers, the ventral pathway is traversed and a letter is identified usually within 150 milliseconds (Petit, Midgley, Holcomb, & Grainger, 2006).

This processing hierarchy is supported by analyses of anatomical connectivity (Bouhali et al., 2014). The posterior occipitotemporal cortex connects to speech processing regions, such as left inferior frontal gyrus and posterior middle and superior temporal gyri, whereas the anterior fusiform shows connectivity with more anterior temporal regions that are important for semantic processing. From the visual word form area (VWFA), the electrochemical signals of the visual stimuli move to areas connected to phonology and to meaning. The VWFA has close anatomical connectivity with perisylvian language areas, so it provides an efficient circuit for both grapheme-phoneme conversion and lexical access (Bouhali, Thiebaut et al., 2014). Readers get almost instant feedback about sounds and meaning through recurrent loops. [13]

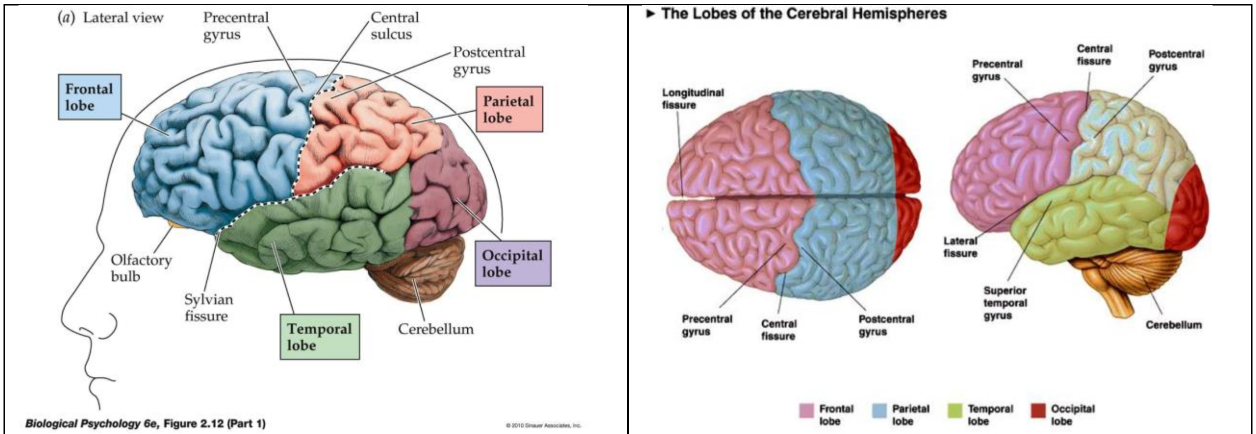
Data from children support the proposed distinction between the phonologically mediated dorsal pathway and the direct print-to-meaning ventral pathway. The phonologically mediated reading is underpinned by a dorsal pathway including the left posterior occipitotemporal cortex, inferior parietal sulcus, and dorsal portions of the inferior frontal gyrus (opercularis, triangularis; Taylor, Davis & Rastle, 2017). fMRI data reveal greater activation for words than non-words in the involvement of the direct pathway, which increases with reading skill. Therefore as children become better readers, reliance shifts from the dorsal to the ventral pathway. Areas of the ventral pathway in English readers increase in sensitivity to written words between the ages of 9 and 15. This increasing sensitivity is associated with speeded word reading ability, though not with non-word reading or phonological processing skill. (Review in Taylor, Davis & Rastle, 2017).

Thus, research with English shows that in the early stages of learning to read, dorsal parietal activation predominates, after which skilled reading utilizes more ventral occipitotemporal areas that also support object naming. The dorsal system may, therefore, be more important when reading is halting and not yet automatic--and in transparent orthographies (like Spanish) which have a consistent relationship between spelling and sound. In contrast, the ventral system may be more important in later stages--when skilled reading is fast and automatic, and in deeper orthographies (like English that necessitate parallel letter processing because of the inconsistent spelling-sound relationships (Aglioti, DeSouza, & Goodale, 1995; Goodale, 2011; Gori & Facoetti, 2013).

One component that is critical for many tasks is **visual working memory** in the parietal lobe (Berryhill & Olson, 2008). In some respects, it resembles a bottleneck, through which stimuli must pass. This type of memory permits the maintenance of object identities and their locations across

[13] Literacy acquisition improves early visual processing and reorganizes the ventral occipito-temporal pathway: responses to written characters are increased in the left occipito-temporal sulcus, whereas responses to faces shift towards the right hemisphere (Dehaene, Morais, & Kolinsky, 2015).

brief delays, such as those accompanying eye movements. It also permits recall of the spatial coordinates. (This may be one reason why early readers must follow their finger and why they become lost if they look away from the text briefly.) The parietal lobe may have a general role in remembering various types of visual information, mainly motor spatial attention and spatial memory. Parietal damage leads to impaired performance on all visual working memory tasks, including spatial, object, and object/spatial conjunction tasks (Berryhill and Olson, 2008).



Figures 3-4. From Gottwald, 2014 (presentation) Citation: Biological Psychology

One way to think about this complex information is the recycling of neurons that are used for multiple purposes. Circuits are working groups that communicate with each other. New connections from older brain structures form new working groups (Gottwald, 2014). Sound-symbol correspondence activates the angular gyrus. The VWFA and angular gyrus do their work so that Broca’s and Wernicke’s areas can interpret the texts. In some respects, VWFA does a visual interpretation task. It stores the visual information of words that we know but it also moves the information over to the right hemisphere. The right part of the brain must be activated when we see a ‘b’ but not a ‘d’ (Gottwald, 2014).

Besides the cortical structures involved in reading, other areas also play a role. The thalamus is located near the center of the brain, with nerve fibers projecting out to the cerebral cortex in all directions. In some respects this structure functions like a switchboard; it collects the signals of retinal ganglion cells, processes them, and plays an important role in the relative weighting of incoming signals (Roson et al., 2019). The pulvinar of the thalamus sends to the cortex signals about sudden, unpredicted motion in the environment. It may facilitate the detection of visual signals that the brain cannot predict, such as a car that suddenly appears or an approaching predator (Roth, Dahmen, Muir et al., 2015). Neuroimaging studies show early involvement of the thalamus in reading tasks, before signals enter the cortex. The thalamus adds context and environmental changes. Also the insula may be involved in the spatial attention necessary to various features (Xue, Chen, & Jin, 2006).[14]

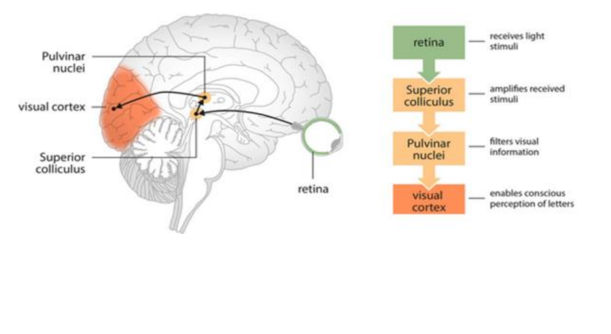


Figure 5. Skeide et al., 2017

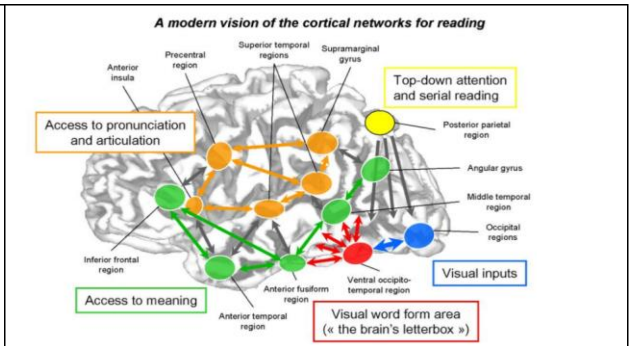


Figure 6. Gottwald, 2014

A study showed that limiting the supply or the function of the neuromodulator adenosine in the auditory thalamus preserved the ability of adult mice to learn from passive exposure to sound much as young children learn from the soundscape of their world (Blundon, Roy, Teubner et al., 2017). An experimental compound FR194921 selectively blocked the A1 receptor; if paired with sound exposure, the compound rejuvenated auditory learning in adult mice. In principle it would be possible to extend the auditory learning window in humans in this way. This method may provide avenues to extend the window of visual perceptual learning.

[14] Temporoparietal connectivity predicts change from childhood to adolescence (Lee, Booth, Chou, 2016). One study highlighted the role of the left posterior middle temporal gyrus (pMTG) as a core node in the semantic network, and cross-sectional studies have shown that activation in this region changes developmentally and is related to skill measured concurrently. There is greater age-related increase in the left pMTG for children relative to adolescents and relatively rapid development before adolescence of semantic representations in the pMTG. Moreover, the connectivity results of pMTG with inferior parietal lobule (IPL) tentatively suggest that early development of semantic representations may be facilitated by enhanced engagement of phonological short-term memory (Lee et al., 2016). Perhaps age may somehow affect connectivity, but results are due to practice of reading increasingly longer texts. Educated adults have developed this connectivity in their native scripts, although illiterate adults may lack that. So the NAD difficulty must lie some other brain feature.

Chapter 5: The role of implicit memory in reading

Until the point when readers make decisions about meaning, the processes are mainly unconscious. Therefore a brief review is given of implicit memory research.

Very roughly, our long-term memory is divided into two systems: (a) explicit or declarative conscious recollections of events and facts and (b) implicit memory, instructions on how to do things (Squire, 2004). Reading tasks involve both types of memory. Explicit memory involves conscious "knowing that…" whereas implicit memory involves knowing "how to...". **Explicit memory** includes personal recollections (episodic memory) and conscious knowledge of facts (semantic memory). **Implicit** memory includes memory for procedures (procedural memory), priming, conditioned responses, and habituation to the environment. Social learning and adaptive imitation also form parts of procedural memory.

Implicit memory has some noteworthy characteristics. In contrast to explicit memory which is subject to forgetting, it resists decay. Continuous motor skills such as bike riding are learned for life. People show individual differences in learning implicit tasks, but this memory function is not closely related to intelligence (Kalra, 2015; Xue et al., 2006). It is unconscious, so people find it hard to express how they carry out various procedures.

Explicit learning has been linked more closely to the medial temporal lobes of the cortex (Dennis & Cabeza, 2011; Squire & Zola, 1996). By contrast, implicit memory reconfigures functional networks of the brain early on, creating focal points at the cerebellum, the basal ganglia and related subcortical structures. The process disassociates the cortical and subcortical structures. Such information has been derived from studies of motor skills (Janacsek, Fiser, & Nemeth, 2012). Studies on more complex implicit cognitive abstractions similarly show disassociation (Soto, Bassett, & Ashby, 2016). [15] This is why people cannot easily talk about how they carry out procedures.

One important feature of implicit memory is **task specificity**. After participants have trained on and learned a particular task, learning rarely transfers to another task, even with identical stimuli (Szpiro, Wright, & Carrasco, 2014). This suggests that training for one script does not transfer to another. For example, some readers report that automaticity to ধন্যবাদ does not easily transfer to धन्यवाद , even though the Hindi and Bengali syllabaries evolved as separate shapes only about 1000 years ago.

[15] Research on initial category learning shows that accuracy is predicted by increasingly efficient integrative processing in subcortical areas, with higher functional specialization, more efficient integration across modules, but a lower cost in terms of redundancy of information processing. But development of automaticity, assessed as speed of correct responses, was predicted by lower clustering (particularly in subcortical areas), higher strength in cortical areas, and higher betweenness centrality. Thus, multimodal association areas and subcortical structures become progressively dissociated in the development of automaticity during category learning (Soto, Bassett, & Ashby, 2016).

Encoding into implicit memory is roughly possible in two ways. The best-known involves effortful, explicit training: transferring larger chunks from instruction through practice and feedback. This is an efficient computational strategy of the brain (Ramkumar, Acuna, Berniker et al., 2016). Once perceptual and motor skills are transferred into implicit memory, they bypass working memory and are not easily forgotten; even after 12 years there should be familiarity (Larzabal, Tramoni, Muratot, et al., 2018).

Less researched is the ability to learn certain tasks informally without effort or awareness; this is called *implicit learning* (Reber, 1993; Kalra, 2015). For example, people often learn how to dance by watching and memorize the lyrics of a song without conscious effort. Implicit learning seems to occur as an incidental by-product of explicit task performance. Subjects with greater immediate memory processing capacity may be better able to learn, and subsequently exploit, the information available in sequences such as grammatical patterns (Carpicke & Pisoni, 2004). This ability is very valuable, particularly its perceptual learning aspects (see below).

Implicit memory is typically retrieved through priming. Priming refers to information items that we saw, heard, smell, or tasted sometime in the past, which affect our subsequent recall and behavior. For example, the beginning stanzas of a song that we know elicit the next. Priming may affect memory for a year (Perfect, Moulin, Conway, & Perry, 2002). Neoliterates who practice a lot during a certain period read faster, perhaps due to priming, but if they stop for a few days, their speed declines.

Implicit learning tasks resist forgetting, but the reaction time needed to retrieve a certain memory may increase. After a year, subjects who had learned a task performed it but had slower reaction time (Kóbor, Janacsek, Takáks et al. 2017). The original statistical structure is also immune to interference. Learning a similar, though new statistical, structure becomes more demanding. For example, learning new line configurations, after automaticity of a previous set, may inhibit automatic performers to some extent for a while (Kóbor, Janacsek, Takáks et al. 2017). This finding may have implications for educated people when learning new scripts. Other things being equal, they might take longer to automatize shapes that overlap with known features of scripts, compared to people who know no script.

Other researchers of implicit learning show similar results (Dennis & Cabeza, 2011). Young people recruited the medial temporal lobe for explicit learning and the striatum for implicit learning, but both activations were significantly reduced in older adults. The older adults recruited the medial temporal lobe for implicit learning. Young adults demonstrated significant negative correlations between activity in the striatum and medial temporal lobe during both the explicit and implicit learning tasks, but these correlations were attenuated in older adults. Taken together, results support dedifferentiation in aging across memory systems. The study did not point to a precise reason for this change.

For reasons discussed below, letters and words taught to adults seem not to transfer completely into implicit memory. They remain in semantic memory, which is vulnerable to forgetting.

Explicit memory also requires effort for recall, which may be one reason why neoliterates have to concentrate while decoding.

Some evidence from perceptual learning studies may shed light on this issue. One study found poorer performance for unpracticed items in conceptual implicit memory (category generation and category matching), but not in perceptual implicit memory (stem completion, perceptual identification). Retrieval-induced-forgetting effects were limited to tests of conceptual memory (Perfect, Moulin, Conway, & Perry, 2002). Thus letter shapes and correspondences may be consolidated through a perceptual, as well as a conceptual, learning route.

The ability for implicit learning seems to show little variation throughout the lifespan for most tasks. However, experimental stimuli used to study its phenomena tend to be simple. Challenging asks may show greater differences. For example, children memorize long songs or poems effortlessly and, incidentally, and may remember them for decades. By contrast, adults require explicit practice and may forget in their 40s content memorized when they were 30. Perhaps a common memory mechanism automatizes the perceptual and the conceptual tasks, and it must be understood better.

One example of age differences in implicit learning is the discrimination between low- and high-frequency items (Amso & Davidow 2012). Children and adults may use stimulus frequency information to perform various tasks in different ways (Kalra, 2015). In one visual discrimination study, all age groups learned implicitly. But around age 12, children became less able to predict higher and lower-probability events. Performance showed lower sensitivity until the age of 60. By contrast, children and adults of all ages learned these sequences explicitly (Janacsek, Fiser, & Nemeth, 2012). This is potentially an important variable. Acquiring certain new skills is significantly more effective until early adolescence than later in life and before age 60 (Janacsek et al., 2012).

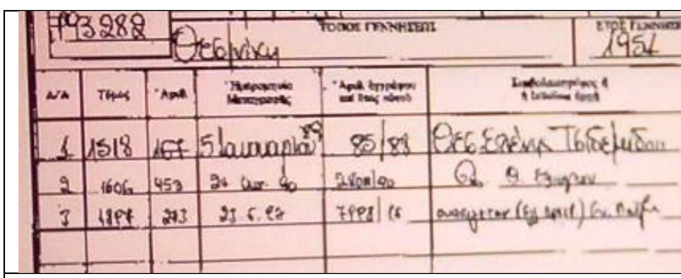


Figure 7. Handwritten land registries in Greece People must quickly decipher such documents

Figure 8. A calligraphic message of wishes in Arabic (Eid kabir Mubarak)

Another aspect possibly related to implicit learning is handwriting. Children practice deliberately, and typically acquire fluent and automatic writing of letters. They may even write without knowing how to read them.[16] However neoliterate adults struggle to write and may form letters deliberately and awkwardly for years. In fact, deciphering fluent handwriting, particularly of earlier periods, may require perceptual learning that develops over several years. Perhaps the guidance from the visual to the motor system is more limited, and research could elucidate the other problems of neoliterates.[17]

[16] These are informal observations in low-income schools. And children may not forget writing, even if they forget reading. For example a Greek in his 70s who had grown up in Egypt, demonstrated fluent writing of his name, though he could no longer read Arabic.

[17] The shorthand systems of the earlier decades were abandoned partly because the writers could not easily read them.

Chapter 6: Statistical learning of visual stimuli

Like many other body functions, the visual system is set up to predict while still in the decision process about a stimulus. The brain performs approximate probabilistic inferences to estimate causal variables in the world from ambiguous sensory data. Nonlinear recurrent neural networks somehow transform the representations of the information (Pitkow and Angelakis, 2018).

Learners' brains must be able to collect statistics about various occurrences. This is also a task for implicit memory (Amso & Davidow, 2012; Kalra, 2015). Statistical learning is a fundamental brain mechanism that extracts and represents regularities within our environment. It results in faster and more accurate responses to high conditional probability events compared to that of low conditional probability ones (Kóbor, Janacsek, Takáks et al. 2017). For example, given syllable X, what is the probability that syllable Y will follow?

Neurons in the later parts in the parvocellular ventral visual stream are tuned to increasingly complex combinations of visual features (Sigurdardottir, Ívarsson et al., 2015). They are related to the extraction of regularities from the visual environment, often without awareness, and they know which image features tend to appear together. Visual experience is thought to play a fundamental role in establishing neural representations that are selective for feature combinations supporting object recognition. Visual practice appears to build neurons tuned to words or word fragments longer than individual letters.

Learning of novel nonsense shapes relies on the medial temporal lobe, a region important for statistical learning (Sigurdardottir et al, citing Schapiro, Gregory, & Landau, 2012). This region has reciprocal connections with the late regions of the ventral visual stream. If such learning is compromised, visual word and object recognition would become impaired. Impairment would leave neurons less selective for such feature combinations and affect the recognition of complex visual stimuli, including letters (Sigurdardottir et al. 2018). For example, dyslexics are impaired at picking up which visual features tend to go together. Thus, neurons in the ventral visual stream, normally shaped by such learning, will not effectively support visual word and object recognition (Sigurdardottir et al., 2017).

Thus there is a positive link between reading ability and statistical learning in the general population. Reading problems are associated with poor recognition of complex visual objects (Sigurdardottir et al. 2017).[18] Deficiencies in visual statistical learning may in some cases prevent appropriate experience-driven shaping of neuronal responses in the ventral visual stream, hampering visual word and object recognition (Sigurdardottir et al. 2017).

[18] The ventral stream has some location information, especially where something is relative to another object. The location system in the dorsal stream is however more where something is in relation to another body part, such as where something is relative to the center of the eye (Heida Sigurdardottir, private communication).

One demonstration of statistical learning is the spelling patterns and the relative ease with which regularities are learned. For example, Indian syllabic scripts show transformations of consonants through a sequence of vowels that has remained constant for many centuries (sometimes called barakhaDi): a aa, i ii, e ee, o oo, etc. Such sequences have been used in many consistent orthographies, such as Spanish and Japanese kanas (ka ki ku ke ko). In English such transformations are less useful, and this may be one reason why children's and adults' methods use them less nowadays. They may also appear "traditional" and not sufficiently innovative.

Given previous observations of reading performance, neoliterate adults experience difficulties related to statistical learning and perhaps prediction of speed. Some issues compromise perceptual learning. Further discussions follow.

Chapter 7: Perceptual learning: Letters as objects, then words as faces

Perceptual learning is a sustainable, long-term performance improvement on a perceptual task following training or visual experience (Watanabe & Sakaki, 2015). The experience or training in a certain task improves sensory processing (Gori & Facoetti, 2013; Maidment et al., 2015). Perceptual learning effects are best understood as a change in the ability of higher-level integration or association areas to read out sensory information in the service of particular decisions (Green, Kattner, & Kersten, 2015). Music, footprints, numbers, X-ray reading also involve this function. It is not enough to know a letter; we must recognize enough of its features in milliseconds in a configuration of many others.

Perceptual learning seems to have evolutionary value for animals, so it is relatively easy and effortless. It mainly happens without conscious effort, in the implicit memory system. Initial exposure leaves traces in implicit memory (Czigler, 2010a; 2010b), that facilitate subsequent performance. The neuronal circuits responsible for visual perception change in the process, as do the connections between the visual and unconscious decision-making functions that identify the various items (Kumano & Uka, 2013). Implicit visuomotor learning is associated with reduced alpha-gamma phase amplitude over the right parietal cortex (Tzvi, Verleger, Muente et al., 2016). High gamma amplitude couples to the theta and alpha troughs and during visual tasks, alpha/high gamma coupling preferentially increases in the visual cortical regions. It seems that low-frequency phase to high-frequency amplitude coupling is modulated by behavioral tasks and may reflect a mechanism for selection between communicating neuronal networks (Voytek et al., 2010).

For reading, our brains must first link together lines perceived by our eye receptors. The visual areas of the brain register these individual features, and, with practice, combine them into the letter shapes used in various cultures. Shapes are perceived most clearly at the center of the eye. Practice rapidly improves perceptual discrimination and detection capabilities, in line with trends of learning curves (Spelman & Kirsner, 2005). For example, in learning to recognize a face or a building, people have an initial period of fast improvement, followed by slow, step-wise, improvement (Aguirre, 2004). Thus, with a few training sessions, medical staff learn to detect tumors in X-rays that initially seemed like vague shadows. Visual discrimination is an implicit memory task, so once it is learned, it is not easily forgotten.

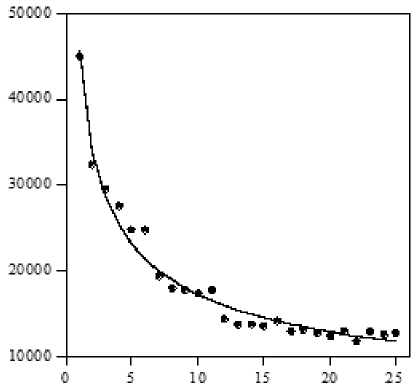


Figure 9. A learning curve depicting the effects of trials over a period of days (Speelman and Kirsner, 2005; reprinted with permission).

People typically think of reading in terms of language, but reading originates as a perceptual process (e.g., Franceschini, Gori, Ruffino, Pedrolli, & Facoetti, 2012; Hari & Renvall, 2001; Vidyasagar & Pammer, 2010). The visual system is optimized to recognize objects, and letters are objects. The brain has certain procedures for learning and distinguishing the shapes of objects. Neural responses to verbal and non-verbal stimuli are reorganized while children learn to read, consistent with visual object recognition (Caffarra, Martin, Lizarazu, et al. 2016; Dehaene, Morais, & Kolinsky, 2015).

In nearly all writing systems, the visual stimuli must be coupled with associated sounds. Perceptual learning competently links visual symbols and sounds, particularly when there is a one-to-one correspondence among them (van Orden, 1987; van Orden, Pennington, & Stone, 2001). Perceptual learning is limited by visual short-term memory, which resides in the posterior parietal region and acts as a bottleneck (Berryhill & Olson, 2008). This cognitive resource declines with aging, particularly among older adults (Wiegand, Lauritzer, Osten et al., 2017).

Fluent reading requires unambiguous deciphering of a text in milliseconds. In highly experienced readers, the speed may roughly match the speed of thought. At a glance you see entire paragraphs of text almost instantly and effortlessly available. Words are clearer in the middle of the visual field than in the periphery. The brain is set up to predict in uncertainty and motion, so you can read ahead and generally make sense of text and of known vocabulary and concepts if you know the language. If you do not know the language, you can read in the same script text almost as easily. Examples would be Hungarian, Turkish, and the many foreign names that readers encounter in print every day (e.g. Dostoyevsky).

Visual complexity strongly affects perceptual learning (Chang, Plaut, & Perfetti, 2016). The more complex the shapes, they longer they take to automatize. There are also limits in the number of symbols that can be easily learned, perhaps because the “objects” are too many, and distinctions overwhelm the statistical learning function.[19] Mere exposure is insufficient for training, as generations of teachers can attest. The 52 or so Latin letters or the syllabic matrices require systematic instruction. Spelling irregularities exponentially increase the hours of practice needed for automaticity, and syllabic scripts similarly need considerable practice, even if they are used to spell languages transparently. As mentioned earlier, the dorsal stream must be trained.

	
Figure 10. Children's shape memory Khmer characters[20]	Figure 11. Elderly learner shaping letters in Nepal

However, individuals improve at many perceptual tasks by performing them again and again. And after much practice, learning may occur even when stimuli may be presented briefly. The brain acts as though it is still engaged in the task, when we are not, and learning still takes place (Wright, Sabin, Zhang, et al. 2010). Pattern analogies, clearly a statistical learning function, help a lot. They enable the brain to take in a set of symbols and, with practice, use the pieces to create larger units; and ultimately to compose complex configurations.

Visual discrimination performance improves for 48-96 hours after initial training, without intervening practice, provided the learners sleep within 30 hours after training (Stickgold, James, & Hobson, 2018).

People certainly learn to recognize many and intricate objects in adulthood, but they have a poor recall of meaningless shapes (Rock & Gutman, 1981). Learning of novel nonsense shapes relies on the medial temporal lobe, a region that is important for statistical learning (Sigurdardottir et al, citing Schapiro, Gregory, Landau, 2012), so this may lead to a potential explanation.

There is a temporal window, a critical period during which the visual system is highly plastic in one's early life; it goes through a major rewiring that leads to the acquisition of important visual abilities. However, it is possible for an adult to acquire a new skill after the critical period, such as detecting abnormalities in X-rays or determining the sex of a chicken (review in (Watanabe & Sakaki, 2015). Thus, training older people can restore abilities that have declined with aging

[19] One example of the distinction needed is the (Japanese) name Tanaka written in Sinhalese තනක . The reader must instantly identify a single and small feature of difference between the ka and the na and a single point between the ta and the ka.

[20] http://www.flexlearnstrategies.net/daily-news-flash-795/

(Anderson, 2012 in Watanabe & Sakaki, 2015). At least some of these functions occur in the V1 primary visual area of the cortex.

Task-relevant perceptual learning of a feature results from training of a task on the feature relevant to the task. Task-irrelevant perceptual learning results from a task irrelevant to the trained task. Feature-based plasticity may be a change in the representation of the learned feature, and task-based plasticity is a change in processing of the trained task. If a task irrelevant feature is strong, then it is suppressed by the cognitive system. Task-irrelevant learning occurs only when task irrelevant feature signals are so weak that they are not detected and suppressed by the attentional system (Watanabe & Sakaki, 2015). In reading, perhaps both types are relevant. Task-irrelevant learning may be one reason for difficulties in deciding relevant and irrelevant features of letters. There seem to be implications for reading that are unclear, because the various experimental tasks involved very different stimuli.

As the difficulty of a task increases, an increasingly smaller visual area is involved. If fine-grained orientation discrimination is required, a lower visual area that processes finer orientation and location signals needs to be used and learned, and attention is an important factor (Hochstein & Ahissar, 2002 in Watanabe & Sakaki, 2015). Some types of perceptual learning depend on perceptual constancy (perhaps like calligraphy), that is a stable representation of certain properties of an object, despite variable visual input. Perceptual learning may occur because of improved filtering of external noise or removal of internal noise. Learning can result from weighing changes in the feed-forward connections between the thalamus and the V1 area (Benjaki et al., 2011 in Watanabe & Sakaki, 2015).

In adult literacy perhaps a deficit emerges with complex letter sets and infinite permutations. The research into learning complex high- vs. low-probability events seems relevant (Janacsek, Fiser & Nemeth, 2012). Specifically the authors tested the probability of detecting triplets of stimuli, which resembles reading acquisition. Raw reaction time exhibited a rapid decrement around age of 12.Thus acquiring certain new skills is significantly more effective until early adolescence than later in life and before age 60.

If the learning of a large symbol set is affected by age, there must be other examples of learning difficulties in complex patterns. Sight reading of music notation is such an example (Dekker, 2015).[21] Jazz musicians who play by ear rarely become able to learn and follow notes in musical scores. Another one is air traffic control. Air traffic controllers have multiple simultaneous challenges, involving implicit conceptual and perceptual learning, as well as dynamic visual movement (Heil, 1998). Training showed age differences on multiple variables, such as slower reaction time. Trainees beyond age 40 exhibited greater difficulties than younger people in grid-matching or congruency-plotting tasks under paced and un-paced conditions (Cobb, Lay, & Burdette, 1971). As a result of such tests, age 30 is the latest age the FAA in the US permits training, and retirement is mandatory at 56 years of age.

[21] One colleague who was fluent in reading and playing different musical keys learned in childhood noticed that he detected more slowly transformations in a key he learned as an adult.

These visual detection tasks can be similar to scanning text and the identification of symbol meaning, while grid matching difficulties may be relevant to the use of limited features in scanning difficulties that are reported by informants, even after 40 years of working with a script learned at age 18.

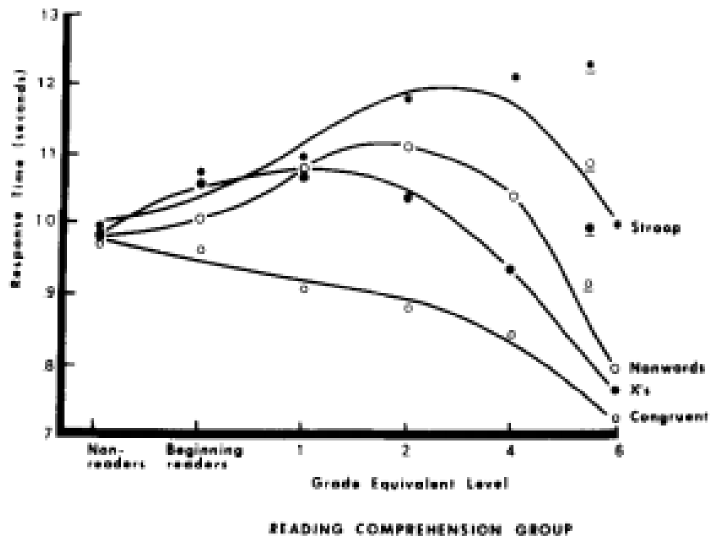


Figure 1. Mean response times in each stimulus condition as a function of reading skill in Experiment 1.

Figure 12. Stroop tests at various reading skill levels

Automaticity can be assessed through Stroop tests. No studies were found on adults. However, one study using English in the US' found that reaction time to known English words decreased every year. By contrast, reaction time to conflicting colors and meaning (e.g. a "red" written in green letters) increased gradually from non-readers to beginning readers, and gradually decreased after grade 4 (Schadler & Thissen, 1981).

Chapter 8: Feature integration in perceptual learning

As mentioned above, our brains must first link together the lines perceived by our eye receptors. The visual areas of the brain register these individual features, and with practice they combine them into the letter shapes used in various cultures.

Spatial attention seems to bind visual object features (such as shape, orientation, or color) that co-occur at the same location and integrate them into a coherent object representation. When multiple objects are simultaneously present in a scene, the visual system must integrate correctly the features associated with each object and also separate them. Practice in perceptual learning tasks integrates features and results in larger shapes, but questions of how this happens have been asked for decades. The feature-integration theory of attention suggests that attention must be directed serially to each stimulus in a display whenever conjunctions of more than one separable feature are needed to characterize or distinguish the possible objects presented (Treisman & Gelade, 1980).

The processes underlying feature integration create the gestalt phenomena that were noted since the 1930s. Circles that are almost closed are seen as completed, and interrupted lines are seen as whole. Bottom-up processing evolves into "holistic" processing, as different parts are "glued" into a whole.[22] Thus perception is parsimoniously organized, and redundant details are not encoded. Grouping and averaging enable the visual system to circumvent capacity limits, minimize errors with which individual items are encoded, thereby optimizing the efficiency of visual short-term memory (Corbett, 2016).

The cue-combination literature shows that cues combine efficiently only if they are perceived as aspects of the same object. Presumably such cues find their own way through the brain to arrive at the same object representation (Dubois, Poeppel, & Pelli, 2013). Disrupting the Gestalt cues that group facial parts together (e.g., similarity and continuity of background colors) reduces holistic processing of faces (Curby, Goldstein, & Blacker, 2013). Increasing feature separation also attenuates the gestalt function (Zhao, Buelthoff, & Buelthoff, 2016).

Features are discrete components of an image that are detected independently of each other. Two steps, detection and combination, may be learned at different rates. Learning of familiar letters is slow and has been attributed to improved feature detection. Unlike the slow learning of familiar letters, the learning of new letters is initially fast, but slows as the letters become familiar. Learning might involve improvement at either step. Identification involves both detecting and combining features, so when identification performance improves, it is important to understand how much of this learning is due to improved detection vs. improved combination of features (Suchow and Pelli, 2013).

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[22] Holistic processing is often considered a sort of template matching without any features. Then there can be feature-based processing that is nonetheless possibly done in parallel. Holistic processing in dyslexic readers appears intact (H. Sigurdardottir private communication).

Shapes are perceived most clearly at the center of the eye. For maximal reading efficiency, there are optimal letter sizes and distances between them (critical size and spacing).[23] Initially, letters require large and spaced letters, but with practice we become habituated to smaller stimuli that are barely separated or are calligraphically connected (Pelli, Burns, Farrell, et al., 2006; see Marinelli et al., 2011 for a review.) Dyslexics increase reading speed as a function of spacing (Zorzi, Barbiero, Facoetti, et al., 2012). At least some of them seem to have a difficulty in dealing with high spatial frequency information. Informal observations suggest that spacing and size strongly influence the reading spee of beginners.

Feature integration seems very relevant to reading, particularly for scripts with several letters that consist of multiple separate parts (such as " i " in Latin script). Multipart letters, as in Arabic, may not be perceived quickly as being parts of the same object.

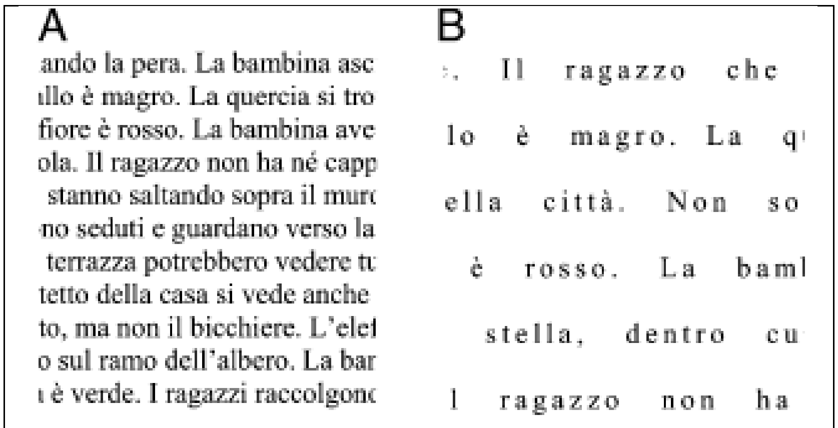

Figure 13. Regular and wider spacing (Zorzi et al., 2012)

Reading an hour a day for a year means identifying millions of letters and words. Each letter is a good basic-level object: simple, common, useful, and with its own name and shape. Identifying a letter requires two steps of visual processing: the observer first detects the letter's features and then combines them to recognize the letter. The slope of learning to detect features is shallow, whereas the slope of learning to combine features is steep (Suchow & Pelli, 2013). This can explain the effects of stimulus complexity and familiarity on the rate of learning. Complex objects (requiring discrimination along many perceptual dimensions) are learned faster than simpler Gabors,[24] and unfamiliar objects are learned faster than familiar objects. Suchow & Pelli suggest that complex objects are learned more quickly than Gabors because complex objects require combining. The implications for letters are unclear.

[23] Critical spacing is the minimum distance needed between a target and flankers to allow recognition. Critical spacing is equal across parts (Rosen, Chakravarti, & Pelli, 2014).

[24] Gabors are shapes with varying light and dark gradations.

Some aspects of gestalt perception seem to decline in older subjects. Usually, the smaller the letters are in the pattern, the easier it is to perceive the larger letter. This was indeed true for the younger participants in a study, but older people remained slower to notice the global figure. Aging brings about changes in the ability to concentrate on one item, while ignoring others (Straudinger, Fink, Mackay & Lux, 2010). Also age seems to restrict the visual working memory (Wiegand et al., 2017), so that fewer features get identified at one time and whole shapes may not be easily detected. However, this decline would not affect 20 year olds.

Pelli, Burns, Farrell & Moore (2006) found that human observers need 7 ± 2 feature detections for threshold letter identification for all traditional alphabets tested, over a 10-fold range of complexity, assuming that feature count is proportional to complexity, even if the least-complex alphabet tested had only seven features per letter and the most complex had 70 features per letter. Thus the seven features detected at the threshold for letters are only a small fraction of features.

Comparing across studies in the literature, Suchow & Pelli found that learning to identify stimuli that require combining, such as unfamiliar faces (slope b = -0.40), bandpass-filtered noise textures (-0.26), 4x4 random-checkerboard patterns (-0.16), and compound gratings (-0.21), is much quicker than learning to detect a Gabor (-0.03, -0.06), which does not require combining. However, combination learning soon saturates, as the letters become familiar. Extrapolating the fitted line for human combination predicts that efficiency would reach 100% (ideal combining) **after 1 million trials**. Typical advanced readers read a million letters every 2 weeks, for years. After so much experience, that combination learning transfers across mild transformations, but detection learning does not. In human observers, the steps are separable: overall, composite efficiency is the product of the composite efficiencies of the two steps.

Thus, for identification of an object from an arbitrary set, measuring the partial transfer of learning across a mild transformation, like scaling or translation, would distinguish the contributions of both steps: feature detection and combination detection is inefficient and learned slowly. Combining is learned at a rate that is 4 times higher and, after 1,000 trials, 7 times more efficient. This difference explains much of the diversity of rates reported in perceptual learning studies, including the effects of complexity and familiarity (Suchow & Pelli, 2013).[25]

It may be possible to use regularities in feature integration to speed up letter detection consciously, at least in the French language. A study used "bubbles", a classification image technique, to reveal the letter areas responsible for the accurate identification of uppercase Arial letters in space – time. The results showed the relative importance of the letter features of some letters across time, demonstrating that letter features are not always extracted simultaneously at constant speeds. Furthermore, of all the feature classes proposed in the literature**, line terminations and horizontals appear to be the two most important features for letter identification** (Fiset, Blais, Arguin et al., 2009).

[25] Sensitivity is (one over the human threshold) or efficiency (ratio of the best possible threshold to the human threshold). Whether presented to eye or ear, efficiency for detecting a short sinusoid (tone or grating) with few features is a substantial 20%, while efficiency for identifying a word with many features is merely 1%. The low human sensitivity for words is a cost of combining their many parts. There is a dichotomy between inefficient combining of adjacent features and efficient combining across senses (Suchow & Pelli, 2013).

This study was conducted with automatic readers and a familiar alphabet, and the specific findings regarding its features are probably not generalizable. Nevertheless, it offers a potential technique in researching the features of other scripts with beginning readers, in hopes of emphasizing the important features.

Feature integration lies at the heart of adults' problems. Despite years of practice, educated neoliterates simply cannot identify enough features per unit of time. Highly educated people must make inferences about a text on the basis of very few features. Inevitably some inferences are incorrect or insufficient, and they may not permit reasonable text processing.
In Arabic, where some letters are obligatorily connected or separated from others, efficient feature binding is crucial. A childhood reader would keep the right number of dots above each vertical line. The features should be binding each letter with its dots, but they do not. Instead the good continuation seems to prevail, linking connected lines together. In contrast to a child, an adult learner may see a cloud of dots hovering above a set of lines. See for example:
ينبغي , a running series of similar letters, such as ينتشر and ينتثر .

Table 1. *Average number of bubbles required to maintain performance at 51% correct at the end of the experiment*

	Number of bubbles
A	50.0
B	84.6
C	78.2
D	58.2
E	68.2
F	82.1
G	58.8
H	38.2
I	132.0
J	94.7
K	38.9
L	92.4
M	47.8
N	43.7
O	108.2
P	88.7
Q	91.4
R	72.9
S	59.1
T	47.9
U	62.2
V	59.4
W	39.1
X	40.6
Y	46.4
Z	45.4

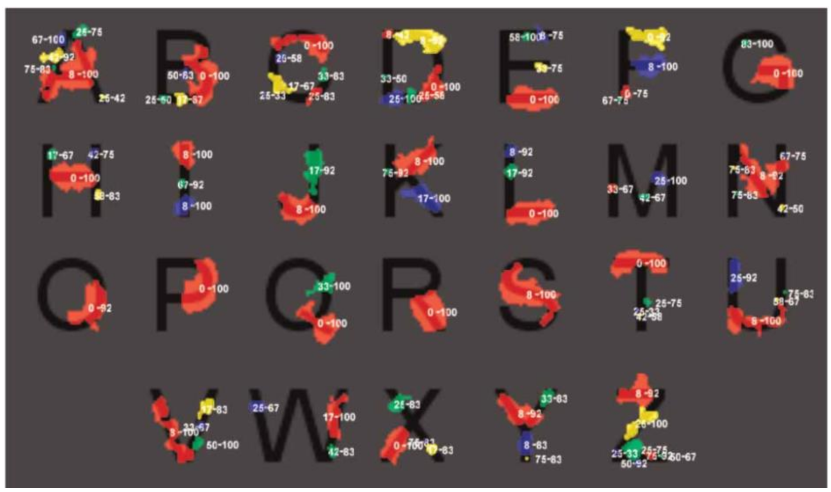

Figure 14. Colors show space-time clusters (collapsed on the time dimension) significantly correlated with correct letter identification superimposed upon the appropriate letter. Four colors were used to help cluster segregation. The numbers in white near each cluster indicate the beginning and end of this cluster relative to stimulus onset.

The effect may be more pronounced when there are dots above and below the line. The limited binding of letters into the spatial arrangement of words, suggests involvement of the dorsal path. Furthermore, letters may be instantly and correctly recognized in some combinations but not in others, depending on the neighborhood. This could also be due to priming from a previous word.

As mentioned earlier, reading calligraphic or artistic letters is a perennial problem for adults. Calligraphic shapes differ significantly from prototypes in various dimensions. In children's minds, a prototype is somehow created, and children perceive deviations as variations of that. By contrast, adults perceive entirely different shapes. Statistical learning deficits may be responsible, but the specifics are unclear.

Identification is not just a single action. Experiments using images on a computer screen showed that the proximity of objects that surround what a viewer is trying to focus on also determines how quickly a viewer can search out the target object (Motter & Simoni, 2007). Crowding may be based on the tuning selectivity for stimuli within a receptive field, and potential neural correlates in cortical area V4 may be involved (Motter, 2018). Thus, the tendency of adult neoliterates to process crowded stimuli slowly, or to skip features, may be related to changes in the V4 area.

Crowding, the inability to recognize objects amidst visual clutter, is known to play a role in developmental changes in reading speed; and is subject to age effects. Compared to young adults, older adults exhibited significantly slower reading speed (a decrease by 30%) and larger crowding: an enlargement of the crowding zone (an increase by 31%) and shrinkage of the visual span (a decrease by 6.25 bits). Researchers also observed significant correlations between reading speed and crowding measures (Liu, Bhavnika, & Kwon, 2017). This finding has implications for older illiterates, who sometimes enroll in literacy classes.

Crowding and letter identification difficulties should not just be considered at the level of individual letters. The neighboring letters play a role in identification. Some letters are more easily identified when flanked by certain others, and crowding of crowding may lead to uncrowding (Manassi, Sayim, & Herzog, 2013). However, the implications and potential training value of this finding were unclear.

Feature integration properties are also used in the recognition of faces (e.g., connectedness between elements, closure, good continuation, emergence of new properties when parts are changed; Wagemans et al., 2012). As mentioned below, face recognition properties are highly relevant to reading.

Sensitive periods in neurons related to perceptual and motor functions

The multiple accounts of inefficient reading acquisition past adolescence suggest the existence of a sensitive period affecting the early parts of the visual system, feature integration, or face recognition. It is as if someone climbed up a ladder on a tree, built a house there, and then threw away the ladder. Residents can climb up and use the house but can't build another one. Why would the visual system have neurons with sensitive periods, where are they located, and what would be their effects?

The properties of critical periods or "sensitive" periods have become better understood.
Reduced neural plasticity may be due to various factors. Neuronal connections may be somehow depleted; initial learning (or lack thereof) may reduce the system's ability to detect changes in the environment that might trigger further learning (Thomas & Johnson, 2008). Prior experience

may place the system into a state that is non-optimal for learning the new skill, and reconfiguring the system for a new task may take longer than it would have taken, had the system been in an uncommitted state (Thomas &Johnson, 2008). Astrocytes constantly nibble at synapses throughout development and adulthood, in a 'use-it-or-lose it' fashion: busy synapses are spared, while unused ones are eaten or become decrepit (Clarke & Barres, 2013).
Under certain circumstances, microglia treat synapses like invading microbes and prune them (Paolicelli et al., 2011). It is reasonable to hypothesize that learning a complex set of shapes may be deemed unnecessary after a certain age.

Declining functions may also be expressed in terms of neuronal coupling. Perhaps ripples of electrochemical signals may not be synchnronized, and thus, certain brain regions may not couple efficiently (Khodagholy, Gelinas, & Buzsáki, 2017). Adult neoliterates may not show a reduced alpha-gamma phase amplitude coupling over the right parietal cortex, that is associated with implicit visuomotor sequence learning (Tzvi, Verleger, Muente et al., 2016). (The researchers used a serial reaction time task that could be used to explore early reading tasks.)

Sensitive periods affect certain perceptual and motor skills early in life (Thomas & Knowland, 2009). Higher-order functions pertaining to abstract thought, such as analyzing or learning grammatical rules, are not very sensitive to age changes; people seem able to learn explicitly the reading strategies and letter shapes even in old age. The hypothesized sensitive period(s) affects implicit memory. Thus the reduced plasticity of a "low-level" function may affect complex behaviors that depend on it.

During critical periods of development, experience shapes cortical circuits, resulting in the acquisition of functions used throughout life. The visual cortex exhibits critical periods in various aspects. The classic example of critical-period plasticity is ocular dominance plasticity, which optimizes binocular vision but can reduce the responsiveness of the primary visual cortex (V1) to an eye, providing low-grade visual input. Some circuits related to feature integration are known to have a sensitive period. For example, children with cataracts, who were deprived of good visual input from faces before the age of 6 months, showed lasting impairment in acquiring 'configural' face processing skills, an expert level of face recognition involving the integration of facial features (Le Grand, Mondloch, Maurer & Brent, 2004). Other areas may also have such effects, so **neoliterate adult dyslexia** is possible.

The brain learns to integrate visual inputs from the two eyes in the cortex, but it needs input from the thalamus to integrate binocular inputs (Roth et al., 2015). To improve developmental problems due to critical periods, reinstating flexibility in the visual cortex may not be sufficient. It may be important to focus on the thalamus and the way it preprocesses information before it enters the cortex. Incidentally, the thalamus is where changes are seen by others in literacy (Sommeijer, Ahmadlou, & Levelt, 2017). If some educational interventions can be linked, reading progress may be possible.

A sensitive period for reading automaticity is reminiscent of language learning in childhood. In fact, many people who hear about **neoliterate adult dyslexia** (NAD) instantly say that this should be expected, given the difficulties adults have in learning languages. However, the brain functions and consequences are different. The effortless, implicit language learning of youth declines, but explicit memory and complex cognition can take over. Grammar books and courses enable people to perform very well, although the accent and the grammar may always have deficits. However, no educational treatments known in 2018 seem able to replace the ease of childhood reading automaticity.

Changes in processing speed throughout the lifespan

Speed is crucial for processing text, partly due to working memory limitations. What is known about processing speed throughout the lifespan? Some of the changes highlighted may be relevant to adult literacy.

Processing speed peaks in a person's late teens and starts declining at 25 (Hartshorne & Germine, 2015). Typically, processing speed increases in childhood, but the increase slows down in adolescence in comparison to adulthood (Miller & Vernon, 1997). Several studies document a further slowdown of perceptual speed with age (Ghisletta & Lindenberger, 2003; Heil, 1998; McCabe & Hartman, 2008), but they pertain to middle ages and beyond, not to age 19. Also changes in knowledge are influenced by perceptual speed (Ghisletta et al., 2003). As mentioned elsewhere, age seems to restrict visual short term memory (Wiegand et al., 2017), so that fewer features get identified at one time and whole shapes may not be easily detected.

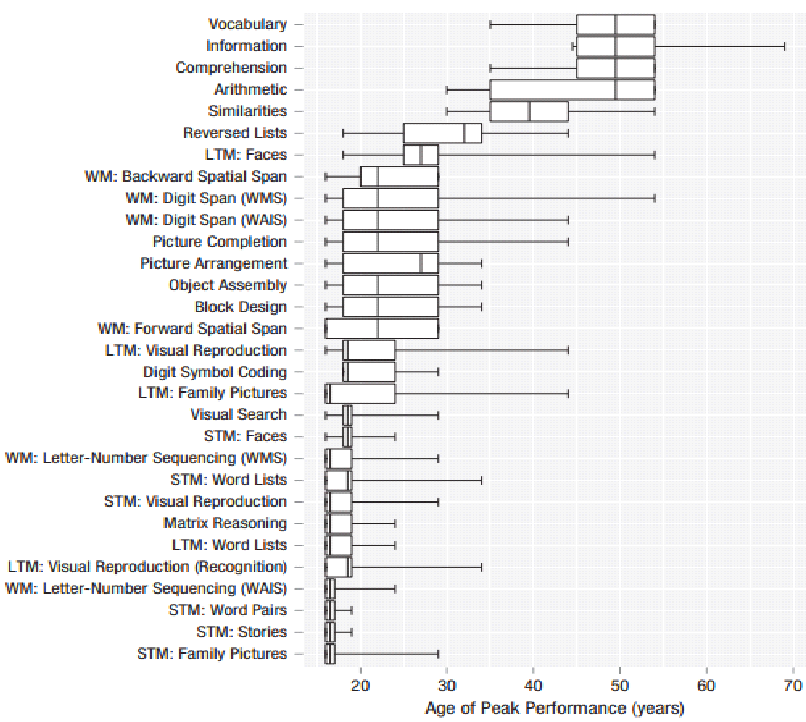

Figure 14. Peak performance ages of various skills

Many relevant skills peak early; such as picture completion, object assembly and forward spatial span. Visual reproduction peaks before age 20, visual search and short-term memory for faces and family pictures peaks around age 20, visual reproduction peaks in the teens and visual recognition peaks around age 20. There is much variance, and the declines thereafter are very gradual. But the data offer an additional variable to consider for the processing difficulties of adult neoliterates.

As for implicit learning ability, it seems to show little variation throughout life (Kalra, 2015). However, complex stimuli may reveal deficits that have not been researched, such as the difficulties of pattern learning in air traffic control.

The role of the visual word form area (VWFA) and face recognition

As outlined above, readers require perceptual learning before accessing language and written concepts to competently link visual symbols and associated sounds. Letters are the most efficient unit of instruction (Pelli, Burns, Farrell et al., 2006), particularly in transparent orthographies, where each letter corresponds consistently to a sound (van Orden, 1987; van Orden, Pennington, & Stone, 2001).

Initially students consciously and laboriously pair letters with sounds. By pronouncing the letters together, students get feedback from the process and "self-teach" (Share, 1994; Zeigler, Perry & Zorzi, 2014). Practice compiles small units into larger ones through detection and combination. Reaction time to letters initially drops fast and later levels off, as with other perceptual learning tasks (Aguirre, 2004; Speelman & Kirsner, 2005). Interestingly, slight variations in the practiced stimuli facilitate consolidation (Wymbs, Bastian, & Celnik, 2016), perhaps by collecting statistics on the features that really matter. The more attention we pay to a stimulus, the better our visual perception becomes and the more effective our visual cortex is at processing that stimulus (Arsenault et al. 2013). Gradually the process changes from conscious and effortful to become implicit and relatively effortless.

After several aggregate hours of practice, processing progressively moves to the visual word form area (VWFA) of the fusiform gyrus.[26] This grouping process seems similar to composing faces out of eyes, nose, cheeks, and lips. The latter apparently happens in the fusiform gyrus, an area that recognizes faces. In that area, multiple shapes are processed simultaneously; that is, they are processed in parallel, rather than serially, letter by letter. This has been called the 'visual word form area' (VFWA). Research shows involvement of the fusiform gyrus in reading, musical notation and numbers (e.g., Dehaene & Cohen, 2011; Dekker, 2015).

The face recognition function provides flexibility in recognizing words. We identify cursive and decorative letters, just as we identify people in profile and sideways, with or without long hair.

[26] When identification of letter stimuli becomes totally effortless, activation is again reduced. The visual system can handle many elements at the same time if only physical features are being processed. When semantic meaning is being processed, a serial bottleneck limits parallel processing (White, Palmer, & Boynton, 2018) and imposes limits on the amounts that can be read at one time.

The ease with which we identify multiple people in a meeting helps us scan text and identify hundreds of words on a page. If humans only read one or two letters at a time, humanity would have remained illiterate.

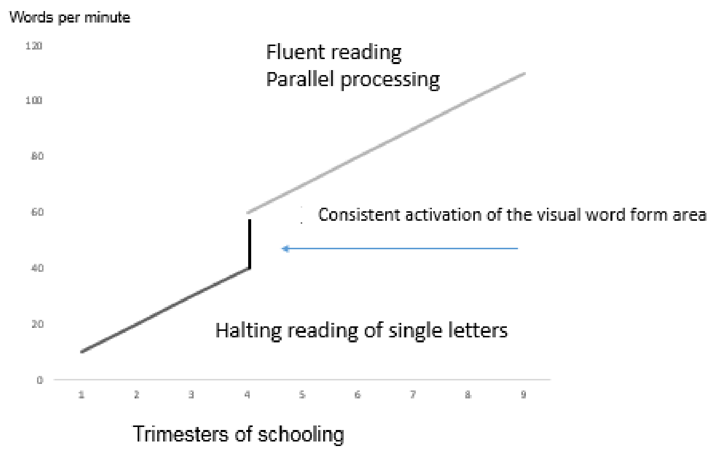

Figure 15: An illustration of serial to parallel processing transition in early reading

The VWFA responds to nonsense letter strings (e.g. cvgzm, wchse). Responses depend on how often the letter combinations occur in the person's native language. Experiences with statistical regularities of novel letter-like shapes lead to increased activation of this region (Pegado et al., 2010 in Sigurdardottir et al., 2017). For example, neoliterates seem able to decide quickly if a letter sequence is "grammatical" or not. For example, one may easily determine that एयर इंडिया is Air India, a set of English words. Some statistical learning clearly has taken place, but the characters are still partly detected, and identification slows down due to the unusual morphology.

More detailed research in 2018 suggests that children use some weakly defined areas in the VWFA for reading rather than face areas per se (Dehaene-Lambertz, Monzalvo, & Dehaene, 2018).[27]

In all cultures people use the same brain structures to read (Perfetti, Cao & Booth, 2013). Depending on the orthographic depth and type of script, the activation patterns may differ, but the same principles apply. [28] In languages spelled consistently, European first graders may attain

[27] First graders were exposed to words, numbers, tools, houses, faces, and bodies while performing an unrelated target-detection task in the first trimester of school. Concurrently, voxels specific to written words and digits emerged at the VWFA location. The responses to other categories remained largely stable, although right-hemispheric face-related activity increased in proportion to reading scores. Retrospective examination of the VWFA voxels prior to reading acquisition showed that reading encroaches on voxels that are initially weakly specialized for tools and close to but distinct from those responsive to faces. Remarkably, those voxels appear to keep their initial category selectivity while acquiring an additional and stronger responsivity to words. Dehaene-Lambertz et al. propose a revised model of the neuronal recycling process in which new visual categories invade weakly specified cortex while leaving previously stabilized cortical responses unchanged.
[28] Chinese characters have a pronunciation and a meaning component (Perfetti, Cao, & Booth, 2013). When people learn to read in English there is almost no activation in the right hemisphere, for spatial variables, but for Chinese

nearly 100% accuracy by the end of grade 1, and may read 40-60 items per minute (Seymour et. al., 2003). Adult students of transparent orthographies therefore can, in principle, attain at least serial processing sustainably.

The neuronal pathways originate from the visual cortex and move forward, linking sounds and subsequently linguistic processes (Gori & Facoetti, 2013). Perhaps the first 170 milliseconds of the process are visual.[29] Linguistic information and comprehension are added about half a second later (Czigler, 2010b) for the N400 event-related potential component. From the VWFA, the electrochemical signals of the visual stimuli move to areas connected to phonology and to meaning. Fluent readers get almost instant feedback about sounds and meaning through recurrent loops. The evidence points to a hierarchical, cascaded, interactive model of word recognition, in which fast feed-forward influences are consolidated by top-down feedback via recurrent processing loops (Dufau, Grainger, Midgley, & Holcomb, 2015).

Thus, reading involves closely timed sequences, where performance at each stage must be optimized to give reliable and timely input to the next. It is necessary to lift the print off the page before interpreting a text. If, for example, an Arabic reader takes 3 seconds to decide whether a middle letter is a sod or a mim, the links further up the chain may not get executed.

Neoliterates must attain the "face recognition" stage in order to process volumes of text and eventually make sense of it. Processing may change reliably from serial to parallel at around 45-60 words per minute (see details in next section). Only when reading becomes fluent can people concentrate on the meaning of the message (Zoccolotti, De Luca, Di Pace, et al., 2005). The research on the relevant reading speed is not specific, but data from Dehaene and Cohen (2011) are suggestive of the above range. When parallel processing is enabled, words acquire the properties of faces; learners can identify handwriting and artistic scripts as deviations from prototypes. However, neoliterates do not progress to this stage. They remain at the inefficient, serial processing stage.

Adults seem able to detect enough features to recognize some frequent words as "pictures" (Pedersen, 2016). Some methods, therefore, teach the recognition of whole words. Aside from the feature integration issues discussed earlier, learning approximate shapes does not really create literacy; letters form an infinite number of permutations. Perhaps there is some value for English and French, but feature integration difficulties must be dealt with.

Facial recognition seems to be fundamentally different from traditional memory in several key ways. It cannot be learned. It is worth examining the relationship between **face recognition**

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there is. By contrast, reading in Chinese results no activation in the angular gyrus, because sound to letter correspondences are unclear in Chinese (Gottwald, 2014).

[29] Accomplished readers of English show early effects of visual stimuli at around 50 milliseconds (ms) after word onset, the earliest sustained orthographic effects at 100-150 ms, and most orthographic and lexical influences arising after 200 ms. Effects of a semantic variable (concreteness) emerge later, at around 300 ms (Dufau, Grainger, Midgley, & Holcomb, 2015). Also artificial neural networks modeling shows that reading can be learned without access to the vocabulary of a language (Pritchard et al., 2016).

abilities and the ease of automaticity acquisition in reading and perhaps in other domains (such as music or X-ray interpretations). The visual word form area (VWFA) also has parts that focus on faces or houses (in the fusiform face area, para-hippocampal place area). But the human brain has a 'super' capacity to recognize faces (Brodwin, 2016). Adults are able to recognize faces better than children, partly because the VWFA grows in neuronal density over time, allowing adults to recognize faces considerably better than children do (Gomez, Natu, Jeska, et al., 2018).

Some people have a slightly larger fusiform face recognition area and are "super face recognizers". A larger VWFA area may compensate for possible deficits in other processing areas and could facilitate reading automaticity in an adult learner. Perhaps less practice is needed for automaticity. One informant who was reported to have a high face recognition capacity, was learning languages in adulthood and was willing to engage with the Persian script. But "super face recognizers" are rare, as are adult script learners, so the overlap is likely to be unlikely.

One noteworthy finding regarding the role of the VWFA is a literacy penalty on face recognition (Dehaene & Cohen, 2011). The VWFA shrinks and slightly changes location. It would be reasonable to hypothesize that people who have learned multiple scripts experience some prosopagnosia, or 'face blindness'. This has been a personal experience.

Some research suggests that face recognition changes in puberty. Scherf & Picci (2016) found that pre-pubescent children had a bias for remembering adult faces, which they called the caregiver bias. In contrast, adolescents had a bias to remember other adolescent faces, exhibiting a peer bias. May this have any relationship to **neoliterate adult dyslexia** (NAD)? Prima facie it seems unlikely.

However, puberty and sexual maturation could, in some way, be related to NAD. Interviews with women raised the concern that a window may close earlier. Perhaps the "age of dyslexia" is related to sexual maturation. There is no research evidence for this concern, but it is something to be watched.

The perceptual learning research suggests that early reading may be a task that is significantly different, and may involve far more elements, than educators are aware of and believe. People can be instructed in the mechanics and specifics of reading, such as letter values and spelling patterns. However, fluency comes about only through practice and unconscious computations of statistical frequencies. Learning letter values and connecting the letters into larger shapes are relatively different tasks. The learning potential and opportunities of neoliterates are likely to be significantly diminished when teaching methods follow common middle-class beliefs (see section below).

Developmental dyslexia - Commonalities with Neoliterate Adult Dyslexia

Countless studies have been published on dyslexia, which is beyond this purview of this article. Dyslexia is linked to multiple types of deficits, but some of the studies related to perceptual learning seem relevant to defining the issues and challenges faced by adult neoliterates (e.g., Tunmer & Greaney, 2010).

The neural signature of dyslexia is a disruption of the posterior reading system (Gottwald, 2014; Shaywitz, 2003). There is suboptimal processing in the early stages of object processing in dyslexia, when integration and mapping of perceptual information to a more form-specific perception memory take place; dyslexics seem to have no problem with integrating semantic information. (Araújo, Faísca, Reis, et al., 2016). There is also widespread activation, particularly in the right hemisphere (Kovelman, Norton, Christodoulou, et al., 2012).

Some research suggests that developmental dyslexia involves deficits arising from the workings of the magnocellular layers of the lateral geniculate nuclei in the dorsal visual pathway. Gori and Facoetti (2013) emphasize the neurobiological basis of attention deficits in developmental dyslexia. It seems that frontoparietal attentional networks sequentially prioritize locations corresponding to successive letters, and, therefore, that impairments to these attentional networks could create reading problems (Sigurdardottir et al., 2017).

Studies of problem readers in various grades have pointed to decoding speed. Normally students read increasingly faster, but dyslexics have difficulties in accuracy and efficiency of decoding, more for pseudo-words than words. Dyslexic children aged 5-7 apparently automatically activate the sound-letter correspondences but perform slowly (Clayton & Hulme, 2018). Dyslexics tend to be 50-75 msecs behind in every reading stage. They compensate in various ways, such as relying more on morphology at the early stages of reading (Žarić, Correia, Gonzalez, et al. 2016). Dyslexics are also more sensitive to word-length effects on decoding, as a result of which phonological abilities lag behind. In the relatively transparent orthography of Dutch, children showed persistent problems with assembling phonology during the phonological decoding of orthographic representations (Verhoeven and Keuning, 2018).

The brains of people without dyslexia are better able to recognize repeated words or images. A comparative study with normotypical readers showed that neuronal groups initially responded strongly and then adapted to a lower level of response. By contrast, brain scans of adult dyslexics showed continued activation, suggesting adaptation difficulties (Peracchione, Del Tufo, Winter, et al., 2016). These effects are observable because, for dyslexics, this is a relatively demanding task. Prima facie, this would be expected among adult neoliterates.

Other studies also show widespread activation, particularly in the right hemisphere (Kovelman, Norton, Wolf, Whitfield-Gabrieli, et al., 2011). Dyslexics have disruptions in the connectivity of neuronal bundles of neurons that link the visual cortex to the visual word form area. In particular, severely dyslexic children show reduced posterior-to-anterior connectivity and disrupted visual processing of words along with a compensatory recruitment of the right posterior brain regions. Patterns of connectivity are consistent with the severity of reading dysfluency (Žarić et al, 2016).

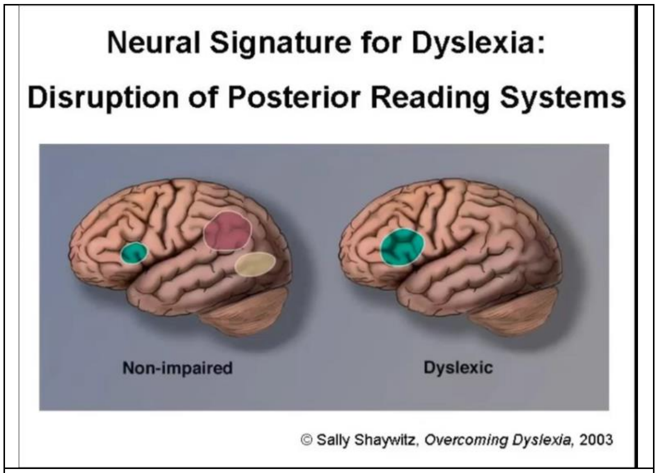


Figure 16. Slide from Gottwald, 2014

Similarly studies of unschooled illiterates suggest that they also recruit the right temporoparietal areas when learning to read (Nuñes, Mestu and Castro-Caldas, 2009). By contrast, control subjects in those studies showed more recruitment of left inferior frontal gyrus.

Developmental dyslexia is also related to specific deficits in processing rapidly presented stimuli or brief sensory stimuli in either visual or auditory modalities (Franceschini, Gori, Ruffino et al., 2012) in the visual word form area (VWFA) at the left ventral occipitotemporal region. In that region, damage can result in pure alexia. It is caused by lesions affecting the prestriate cortex of the dominant occipital lobe (e.g. Fiset, Gosselin, Blais & Arguin, 2006).[30] Specifically, patients with damage to the left posterior occipitotemporal cortex show slow and effortful reading in alphabetic scripts (Roberts et al., 2013). They can only read letter by letter; they confuse letters easily, and they are slow. They may read a 3-letter word in about 2 seconds and longer words in 4-6 seconds each, making it difficult to hold an entire sentence in working memory. They can only hold one or two letters in their visual span (Arguin & Bub, 2005; Henry, Gaillard, Volle, Chiras, Ferrieux, Dehaene & Cohen, 2005; Hanley & Kay, 1992; Pelli et al., 2006). Clearly this pathology does not afflict neoliterates, but it may help point to pathways where the problem originates.

Dyslexic readers are also impaired in their recognition of faces and other complex objects, and show hypoactivation in ventral visual stream regions that support word and object recognition. Responses of these brain regions are shaped by visual statistical learning. This means that normotypical readers retain the combinations of statistically likely features in words and other objects. As mentioned earlier, statistical learning may build an efficient object recognition system with neural mechanisms that extract useful feature combinations based on simpler features that tend to appear together, such as word fragments (Sigurdardottir, Danielsdottir,

[30] It is possible to produce this effect in normal people by spacing letters too far apart, creating low contrast, and taking away gradient information though high-pass filters (Fiset et al., 2006). Treatments sometimes help right-hemispheric structures to develop alternative connections and compensate for the disrupted VWFA (Henry et al., 2005). The splenium of the corpus callosum is frequently damaged in pure alexic patients who are unable to read despite good language function (Carreiras, Vaquero & Lozano, 2009).

Gudmundsdottir, et al. 2017; Sigurdardottir, Fridriksdottir et al., 2018). Statistical learning happens only at selectively attended shapes, but not unattended shapes. **When the features are attended, their statistical relationships are learned.** Inattention would prevent experience-dependent neural plasticity. Partial statistical learning may be happening because all the minimally necessary features are not recognized. Thus, neurons in the ventral visual stream normally shaped by such learning will not effectively support visual word and object recognition (Sigurdardottir et al., 2017).

So, dyslexics are somehow less competent at learning from statistical sampling where features go together. The visual experience of reading is inefficient in shaping their visual system. Similarly, educated neoliterates seem not to not use this object recognition system efficiently.

Structured instruction changes activation patterns, so readers compensate and read faster (Gelbar, Bray, Kehle et al., 2016). But even when they compensate, adult dyslexics are much slower in processing information (Kovelman et al., 2011). Adult dyslexics rely more on the semantic properties of morphemes than normal readers. This probably helps them make sense of the text (Cavalli, Colé, Pattamandilok et al. 2017).

Background 'visual noise' seems to matter, as many dyslexics and educated neoliterates attest. "Busy" graphics significantly slow down letter detection. One study compared normal and slow adult readers on a visual letter detection task that varied in two aspects: the presence or absence of background visual noise, and a small or large stimulus set. The weak readers took advantage of repeated stimulus presentation as effectively as non-impaired readers, but they performed more poorly when high external visual noise was introduced. The results support the hypothesis that a deficit in the ability to exclude external noise, rather than a perceptual anchoring deficit, impairs reading for adults (Beattie, Lu, & Manis, 2011). The neoliterates have difficulty in identifying features when artistic designs are present, so external visual noise is a problem. One example from Arabic, is where the vowel signs compete with the dots above and below letters. Although the dots clarify the vowels, paradoxically it is often simpler to read without them.

The difficulties which neoliterates experience allude to dyslexia, but educated neoliterates are, presumably, normotypical. One way to think about dyslexia is that perhaps in some cases the window of affected people closes earlier. Dyslexics tend to present early signs, such as white-matter deficits in children that are clearly not shared by normal readers (Vanderauwer, Wouters, Vandermosten et al. 2017). In the case of neoliterates a problem area or function must be identified that at least leaves the educated neoliterates' neurons intact.

Dyslexia studies have focused on the ventral path, but a dysfunctional dorsal path in dyslexia is possible. Dyslexic readers appear to have some problems with visual attention, which is mainly a dorsal stream function. A subsequent section takes up this question.

Neurocognitive issues of unschooled illiterates

Around the turn of the 21st century, much research was conducted on the brain architecture of a few remaining unschooled illiterates in Portugal and Greece, using neuroimaging techniques available at the time (Abadzi 2006 review).

The schooling process includes many tasks besides literacy. It changes brain architecture in multiple ways, linking speech and visual areas (Petersson, Silva, Castro-Caldas, Ingvar, et al., 2007; Castro-Caldas, Petersson, Reis, et al., 1998). It seems to create differences in the ways the two brain hemispheres share functions. For example, the corpus callosum of adult illiterates was thinner on the section of interparietal crossing compared to literate adults, and this section did not grow when they were taught to read (Castro-Caldas, Miranda, Carmo, et al., 1999). Illiterates process language less well (Petersson, Reis, Askelöf et al. 2000). A close connection was found between reading and writing when learned in childhood, but adults, when taught to write, seemed to be copying internal images of letters and words and did not develop proprioceptive memories (Castro-Caldas, Nunes, Maestú, Ortiz, Simões et al. 2009; review in Abadzi, 2012).

Illiterates who perform worse than literates on visuo-spatial tasks (Ardila, Rosselli, & Rosas, 1989), and who exhibit less consistent visual scanning paths (Ostrosky-Solis, Efron, & Yund, 1991), show difficulties in discriminating between mirror images (Kolinsky et al., 2011) and maintain a holistic mode of visual processing, rather than adopting analytic strategies (Brito-Mendes, Morais, & Kolinsky, 2005; Ventura et al., 2013). As a result, they have difficulties in processing complex language. These issues alone, in addition to poverty and hard work, makes literacy training challenging, as discussed below.

Chapter 9: Performance of unschooled illiterates during or after reading instruction

A newer wave of studies, starting around 2000, has tracked the literacy progress of unschooled people using more sophisticated neuroimaging methods. These studies found that, when teaching illiterates (for example a study of eight Roma women in Europe), the brain reorganizes to accommodate this new skill (Dehaene, Morais, & Kolinsky, 2015) but the activation patterns only partly resemble those of childhood literates. [31]

Neuroimaging studies show the beginning stages of literacy in unschooled adults. A broad, and more bilateral, ventral visual network recruits additional posterior parietal regions, associated with serial effortful reading. This observation is similar to the way young children initially use a broad bilateral visual network that progressively restricts to the VWFA as performance increases (Dehaene et al., 2010). The changes seem encouraging, and some publications announced them with considerable fanfare. Nevertheless, the findings are fairly consistent: Adult illiterates can learn to decode, but they can only read laboriously and deliberately. Most studies show that the ventral pathway is not engaged or is insufficiently engaged. The visual word form area is not consistently or sufficiently activated.

In a study of illiterate Portuguese and Brazilians who were taught to read, the VWFA showed some activation (Dehaene & Cohen 2011). The researchers tested a group of Brazilian and Portuguese illiterates and ex-illiterates who were taught to read, along with people made literate in childhood. Reading speed was related to the intensity of arousal observed in the VWFA. This region enhances its response to letter strings as soon as the rudiments of reading are in place (Dehaene, Pegado, Braga, et al., 2010; Song, Hu, Li, Li, & Liu, 2010; Yoncheva, Blau, Maurer, & McCandliss 2010). However, the Brazilian and Portuguese neoliterates who were studied read more slowly than childhood literates; they only read 10-25 words per minute compared to 45 or more necessary to understand text. Moreover, brain imaging showed that the neoliterates engaged brain areas associated with effortful serial reading of letters, much like dyslexics.

One European study using magnetoencephalography, found that the process of learning to read and write during adulthood differs significantly from the process of learning to read and write in childhood (Castro Caldas et al., 2009). Visual decoding gives access to the phonological form of the words, which is related to left inferior frontal gyrus. Activation seemed to reflect articulatory rehearsal. This means, again, that the readers read letter by letter and pronounced text subvocally (Silva Nunes et al. 2009).

A structural MRI study of unschooled Colombian guerrillas in their early 20s who had surrendered, found similar results of articulatory rehearsal (Carreiras, Vaquero & Lozano, 2009).

[31] A critical variable is illiterates' attentional control (Kolinsky and Morais 1994). Illiterates may not have trained it on tiny shapes.

In comparison to childhood literates, the neoliterates had anatomical connections linking the left and right angular and dorsal occipital gyri through the area of the splenium of the corpus callosum; It was found that white matter in these brain regions was more dense in late-literates than in illiterates. Increases in grey-matter density were also identified in the bilateral dorsal occipital areas, associated with higher-level visual processing, and in the left supramarginal and superior temporal areas, associated with phonological processing, and also in the angular gyri and posterior middle temporal regions, associated with semantic processing. Reading, relative to object naming, increased the interhemispheric functional connectivity between the left and right angular gyri. The activation in the left angular gyrus exerted top-down modulation on information flow from the left dorsal occipital gyrus to the left supramarginal gyrus. Despite these changes, the guerillas did not engage the ventral system in the left ventral occipitotemporal region. Thus the "anatomical signature of literacy" still involved no automaticity.

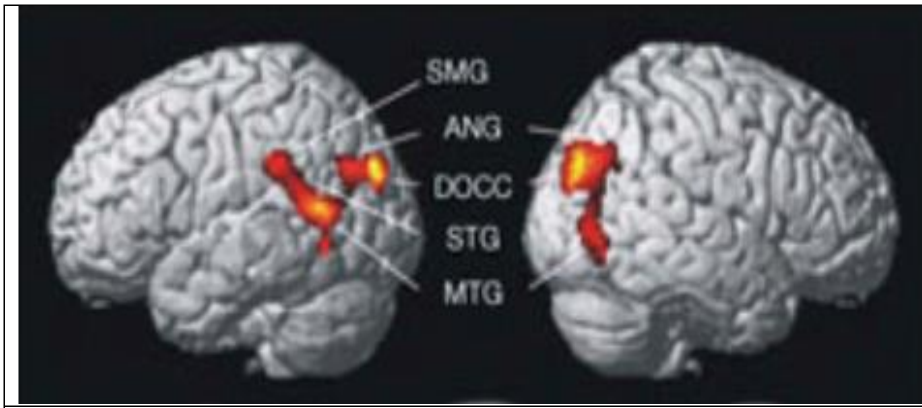


Figure 17. No activation in the visual word form area (Carreiras et al. 2009)

By contrast, in the early stages of learning to read English, dorsal parietal activation predominates, after which skilled reading utilizes more ventral occipitotemporal areas that also support object naming (Taylor, Davis & Rastle, 2017).

A single-subject study of a 45-year old illiterate Brazilian man found that a modest level of literacy was attained over two years. During that period the subject's brain was scanned 20 times. Initially, when exposed to words, the participant did not activate neural circuits for reading, but gradually he began to present activation in the left visual word form area. The increase was accompanied by a decrease in face responses, a result also noted by Dehaene & Cohen (2011). Reading-related responses also emerged in language-related areas of the subject's inferior frontal gyrus and temporal lobe. Additional activations in the superior parietal lobe, the superior frontal gyrus and the posterior medial frontal cortex suggested that the subject's reading capacity remained dependent on effortful executive attention and working memory processes (Braga, Amemiya, Tauil, et al. 2017).

A study in the Dominican Republic explored word recognition automaticity in Spanish-speaking adults who had taken a reading course. The study assessed the event-related potential (N170) for word stimuli. Participants engaged in two reading tasks that varied the degree of attention required for linguistic components of reading: an implicit reading task, in which they detected immediate repetitions of words and symbols (one-back paradigm); and an explicit, reading verification task, in which they determined if pairs of visual-auditory words matched. Results were compared to those of a group of people who learned to read in childhood. N170 amplitudes on left and right occipitotemporal regions were registered for each condition. A left-lateralization of N170 for word stimuli was considered as an index of word reading automaticity. However, no left-lateralized N170 was found for the neoliterate group in either condition. In addition, for the reading verification task, N170 amplitude for words was larger on the right than on the left occipitotemporal region. A comparison group of childhood literates found left-lateralized N170 amplitude for words in both conditions. Findings suggest that the neoliterate group had not yet acquired automaticity of word recognition, but they could be showing evidence of word familiarization. (Sanchez, Avery, Froud, 2017; Sanchez 2014).

Additional analyses by Sanchez, outside of the regions and time window of interest conducted for the reading verification task, revealed a significant left-lateralized response to both matched and unmatched words for the neoliterate group. This component appeared later than the expected N170 peak, over frontal and central sensors rather than occipitotemporal regions. This response could indicate the recruitment of additional cognitive resources for word recognition, a strategy used by dyslexics and by other adult neoliterates (e.g., Dehaene, Pegado et al., 2010). Such recruitment is again associated with serial, effortful and slow reading.

A study conducted in India, using resting-state fMRI, also probed the learning process of unschooled illiterates (Skeide, Kumar, Mishra et al., 2017). It similarly found signs of neuroplasticity and reorganization to make learners increasingly efficient in visually navigating through letter strings. After 6 months of literacy training neuroplastic changes were detected in the mature brain. Literacy-induced neuroplasticity was not confined to the cortex but increased the functional connectivity between the occipital lobe and subcortical areas in the midbrain and the thalamus. Individual rates of connectivity increase were significantly related to gains in individual decoding skills.

Specifically, neural reorganization in Indian participants involved the superior colliculi, a part of the brainstem, and the pulvinar, located in the thalamus, that adapted the timing of their activity patterns to those of the visual cortex. These deep structures in the thalamus and brainstem help our visual cortex to filter important information from the flood of visual input, even before people consciously perceive it. Interestingly, it seems that the more the signal timings between the two brain regions are aligned, the better the reading capabilities. The neuroscientist involved explained further that “these brain systems increasingly fine-tune their communication, as learners become more and more proficient in reading". This could explain why experienced readers navigate more efficiently through a text (Skeide et al. 2017). So perhaps a signal timing issue is involved. Nevertheless, neoliterates showed limited improvement in performance and, after six months, they could read an average of 7.10 words. As with other studies, the BOLT[32] response did not reach significance. The researchers attributed that deficit to the visual complexities of the Devanagari script.

[32] Blood-oxygen-level dependent imaging in the functional Magnetic Resonance Imaging technology (fMRI).

A German study of immigrants (Bolzman, Mohammadi, Samij et al., 2017) compared normal readers to a group of schooled people in Germany who were functionally illiterate. Analyses revealed decreased gray matter intensities in functional illiterates, compared to normal readers, in several reading-related brain regions such as the superior temporal gyrus, supramarginal gyrus, and angular gyrus. Functional illiterates showed reduced fractional anisotropy values in the genu of the corpus callosum. The schooled functional illiterates received training. After that, the differences were no longer statistically different from the pre-test data of the control group, and the increase was positively correlated with reading and writing skills. The findings suggest that poor literacy skills are associated with several structural abnormalities in reading-related brain areas. It also suggests that adults who read fluently, but slowly, may improve reading skills with training. Then the structural brain differences disappear. As mentioned, however, details about reading instruction are rarely given. Thus it is difficult to ascertain to what extent the results were due to neurocognitive variables, or to deficient training. [33]

There have been various **attempts to teach scripts to educated adults experimentally** and to monitor results through neuroimaging. They focused on individual letters and the early literacy stages. Some examples are below.

Chinese adults underwent a 2-week training to learn the 120 characters of Korean script and were scanned before and after the training. Functional symmetry proved important. The participants who showed greater left-hemispheric dominance during the pre-training task had better post-training performance (Xue, Chuangsheng, Zhen, et al., 2006). Thus, individual differences arising from neural factors should be expected in processing novel scripts. Another study involved teaching a few Korean letters to Japanese subjects who were monitored through fMRI (Hashimoto, Ryuichiro & Sakai 2004). In two days the VWFA showed increased neural activation when letters were linked to sounds, and the degree of activation predicted individual performance improvement. In both cases, limited combinations were assessed.

In a similar study, undergraduate university students in the US were taught for about two weeks how to read a fictional writing system named HouseFont, which assigns images of houses to English phonemes. Also Korean letters were used alongside English. Participants achieved proficiency in this pseudo writing system akin to a first-grade reading level, reading around 22 words per minute. After the training, the researchers observed increased VWFA activity that predicted participants' reading speed. This effect was not observed in the para-hippocampal place area—a brain region that has been shown to respond selectively to images of houses. These findings suggest HouseFont was acquired as an additional alphabet (Martin, Durisko, Moore, et al., 2019).

[33] This may reflect the "representativeness bias"; researchers are invariably from middle-income environments, where childhood literacy is often easily acquired regardless of method. Thus, some neuroscientists who were contacted regarded literacy as a language topic.

Taylor, Davis & Rastle (2017) also used an artificial script of a few letters; results are mentioned elsewhere in this text.

Results resonate with the literacy study of Pelli, Burns, Farell, & Moore-Page (2006), who tested learners ranging widely in age (3 to 68) and experience (none to fluent) with many scripts (including English, Arabic, Armenian, Chinese, Devanagari, Hebrew). The researchers used three- and five-letter words, various types of fonts, sizes, contrasts, durations, and eccentricities to assess perceptual learning. They found that foreign alphabets are learned quickly; in just 3000 trials, new learners attained the same proficiency in letter identification as fluent readers. However, learners did not instantly recognize strings made up at random from these characters. They performed poorly, as if they saw them for the first time. Moreover, learners recognized only 1-2 letters per saccade, while fluent readers recognize about 5 letters per saccade. This could be expected, since readers had not been trained to chunk letters together. But the study suggests adults can be trained to perceive individual letters very fast. With computers, thousands of presentations can be routine, though final outcomes would be unclear.

These studies also suggest that the VWFA of adults works well, if it is just fed useful input from the dorsal stream. Literate or illiterate adults do learn sound-letter correspondences and may attain 20-30 words per minute. One study showed continued improvement over a few weeks, with no indication that the participants reached a performance ceiling (Martin, Hirschorn, Durisko et al., 2018). The results could lead to a conclusion that that the issue of **neoliterate adult dyslexia** discussed in this review either does not exist, or is not universal. However, none of these studies followed participants to a reading level needed for relatively effortless information processing of ordinary text. Until mid-2019, no study had been found to suggest that such performance is attainable.

Chapter 10: Educational programs for teaching illiterate adults - Results

The poor results of adult literacy instruction appear to be due, at least in part, to ineffective instructional methods. It would appear that instructional methods derived from the common sense of automatic readers only have had the effect of compromising the fluency of many children worldwide (Abadzi, 2017). Particularly for adults, instructional practice has been led by the views of philosophers, such as Paulo Freire or Fidel Castro of Cuba. Generations of university students have been trained in the belief that adults are self-directed people who need a facilitator rather than a teacher. One common sense idea has been to focus on the meaning of texts and relevance in adults' lives. Textbooks are typically short, with large pictures and small letters, and learners are often encouraged to talk about their social situations rather than read. Instruction focused on whole words and sentences has had poor outcomes. Over-reliance on common-sense approaches has compounded the neurocognitive difficulties of adults. For example, learners of a UNESCO-sponsored Freirean method (REFLECT) in Burkina Faso scored 2.4 points out of 10 in text reading (MEN, 2013).[34] A program for police officers in Afghanistan left 45% unable to read any text (Vaessen, 2016). Similarly, many Ethiopians in Israel failed to learn reading (Fanta-Vagenshtein & Chen, 2010).

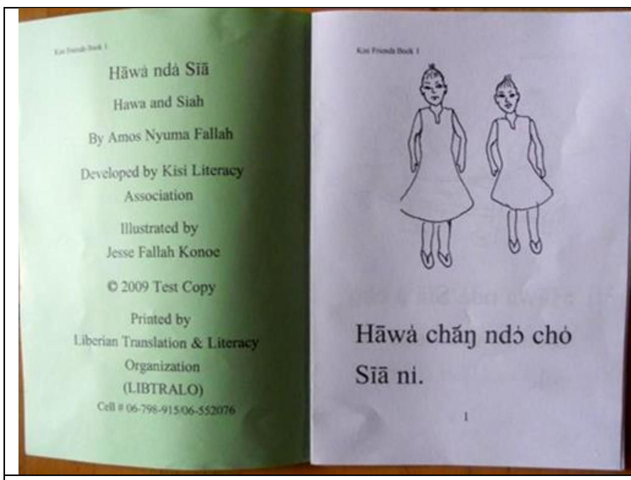


Figure 18. Liberia – Whole-language textbook in a local language (Ramos-Matoussi & Amorim, 2013)

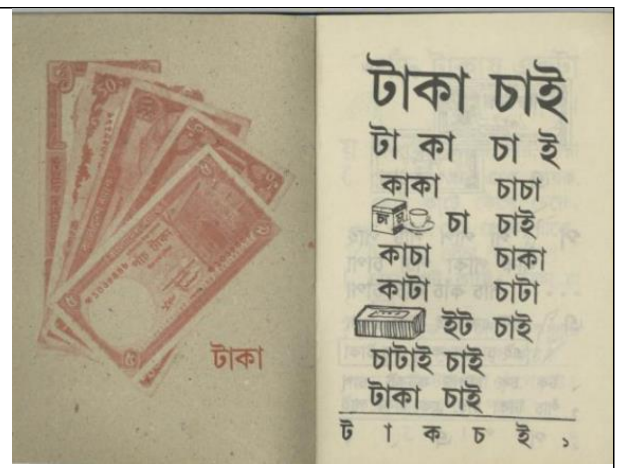


Figure 19. Bangladesh – Ja chai (Mr. Hastings); 5 syllabic complexes on day 1 (author)

Many studies have shown that instruction on individual letters and associated sounds gives much better results than an early focus on meaning (e.g. Taylor, Davis & Rastle, 2017). Better reading performance depends on phonological awareness, letter recognition speed and verbal reasoning (Sebastian & Moretti, 2012). Nevertheless, a number of studies which offered detailed instruction to adults using letter-sound correspondence, still achieved limited results. Below are the results for some programs undertaken since 2000.

[34] Literacy program evaluations rarely report words read per minute. They may various tests or average literacy and numeracy performance with self-reports, such "most significant change" among learners (e.g., Trudel & Cheffy, 2017).

European studies that taught illiterate immigrants language and reading, including comparisons with literate learners, were conducted in order to identify the required conditions for successful integration of illiterate immigrants in a new society (e.g., Kurvers, 2007; Wagner, 2004; Young-Scholten & Strom, 2006). The illiterates were found to have language learning difficulties and also lagged behind on all relevant indicators.

In the **Netherlands**, classes for immigrants were provided in Dutch over several years (Kurvers 2007, 2014; Kurvers & Ketelaars, 2011). Progress was slow for adult first-time readers. In spite of this developmental data, instruction followed the alphabetical principle and stage models of beginning reading and writing provided for young children (Kurvers 2007).

Intensive and non-intensive courses were held. Non-intensive course learners who were given a list of 60 words could read on average 20 words correctly, ranging from zero to 53 words. On average they read 2 words per minute, taking 10.28 minutes. This is very slow, compared to primary school benchmarks. Only one learner who could read 53 words could also read a short text and answer a few comprehension questions correctly; some students could not answer any comprehension question.

Intensive courses showed better performance. On average learners were able to read 50 of the 60 words by the end of the year and could do so in 2.26 minutes. They could also spell 21.3 words correctly. Again, however, they only read about 21 words correctly per minute, which is too low a speed for consistent comprehension.

Table 1. Literate vs. illiterate performance in Dutch language and reading

Means and standard deviation of decoding task, spelling task and reading time after 150–160 hours of instruction in non-intensive and intensive courses

Task		*Non-intensive course Non-literates (N = 8)*	*Intensive course Non-literates (N = 6)*	*Intensive course L1-literates (N = 6)*
Word-reading	Mean	20.6	30.0	42.5
	SD	19.4	19.6	13.8
Spelling	Mean	5.9	13.5	15.8
	SD	7.3	8.5	6.4
Time (minutes)	Mean	10.28	4.03	4.20
	SD	4.49	1.07	2.25

Source: Kurvers (2007, p. 32).

The intensive course group achieved better results after 10 weeks of instruction than the regular-course students achieved after about 40 weeks of instruction. They read much faster, read many more words correctly, and spelled more words correctly. Within the intensive course group, the scores of the first-language literates were better than those of the non-literates on the three measures (see columns 2 and 3, Table 3). This study also revealed significant differences between non-literate and low-educated adults: the average correct score was 42% for the non-literates and 72% for the low-educated readers. Thus, childhood literacy gave an advantage.

Nevertheless, failure rates were significant. About 30% of the students could read zero words after about 850 hours of instruction (about 25 months in non-intensive courses of 6–8 hours a week, or 12 months in intensive course of 15 hours a week). Only about 11% reached the highest level for foreign speakers, after 985 hours on average. A few students attained basic literacy in less than 300 hours, while many others needed more than 1000 hours to reach the lowest literacy levels (A and B). Quite a few needed more than 2000 hours, equating to more than four years in an average course. Reading and writing scores correlated significantly with Dutch contact frequency, with attendance rate and with homework completion. The latter was significant for growth scores in reading. Age correlated 0.22 with reading scores and 0.23 with writing scores.

A similar course for foreigners in **Germany** showed that outcomes depended more on phonological awareness than socioeconomic variables. Literacy training improved decoding and retrieval skills. Nevertheless, after 132 days of literacy training, learners' phonological processing improved but their achievement did not approximate to literates (Landgraf, Beyer, Hild, et al. 2012; means scores reported).

Table 2. Literate vs. illiterate performance in German language and reading

BISC subtests	Illiterate group		Literate group
	Before the alphabetization	After the alphabetization	
Phonological awareness			
Rhyming	38.83 (35.15)	37.26 (33.85)	94.19 (18.64)
Syllable segmentation	57.15 (31.03)	58.21 (31.32)	92.29 (16.57)
Phoneme to word comparison	70.72 (33.25)	80.18 (32.78)	98.46 (8.73)
Phoneme association	**58.85 (34.51)**	**78.64 (28.98)**	93.31 (18.31)
Phonetic recoding in short-term memory			
Repetition of pseudo-words	**65.05 (28.87)**	**74.70 (28.68)**	93.30 (9.68)
Visual attention to words and phonemes			
Word comparison (errors)	90.76 (22.70)	94.12 (17.53)	100 (.00)
Word comparison (reaction time)	**11.61 (16.67)**[a]	**6.55 (8.43)**[a]	1.7 (.10)[a]
Long-term memory retrieval			
Color naming (black and white, reaction time)	62.31 (40.07)	70.12 (39.40)	99.25 (4.17)
Color naming (difference: stroop–black and white)	77.54 (30.60)	85.49 (25.40)	92.82 (17.47)
Average BISC score	**67.07 (16.51)**	**73.59 (15.16)**	95.76 (5.66)

In **Finland**, a course for immigrant women (24–45 years of age) found similar problems. Unlike Dutch, Finnish grapheme-phoneme correspondences are quite regular. But as suggested by Pelli et al. 2006, mere knowledge of the letters did not lead to sound blending. Learners had difficulty connecting strings of letters to words. In addition, phonological working memory was poor, and the necessary vocabulary was difficult to acquire. Multiple pedagogical approaches were needed to accommodate the needs of these learners. (Tammelin-Laine & Martin, 2014).

Evaluation of a literacy program in the Mooré language of **Burkina Faso** in 2001, found that many graduates had retained letter knowledge and tried to use reading and writing. Recent graduates read about a word every 2-2.5 seconds (20-30 words per minute), a speed too slow to retain a message reliably in working memory. Graduates of earlier programs read on average 45 words per minute, as did fourth-grade students in Mooré (Royer, Abadzi, and Kinda, 2004).

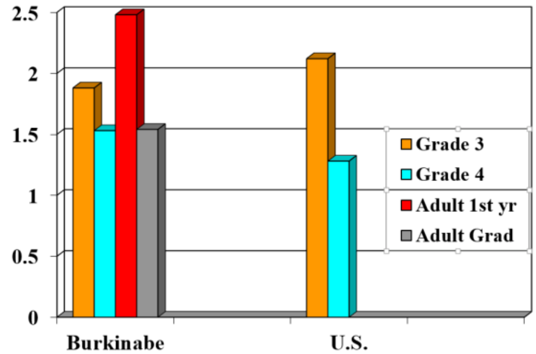
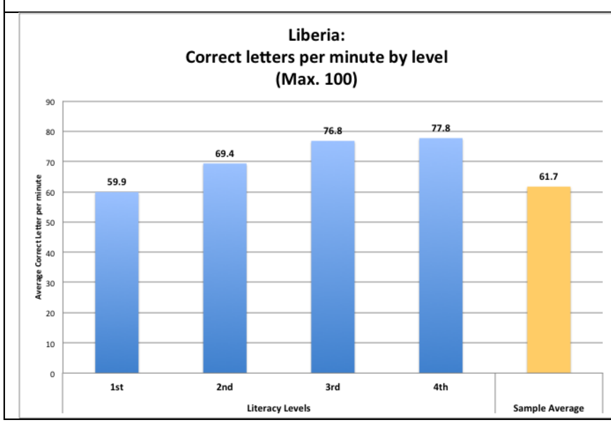


Figure 20. Burkina Faso vs. US; minutes per word

The United States Agency for International Development (USAID) financed adult literacy courses in Angola and Liberia. Portuguese and English, both of which have spelling complexities (Ramos & Amorim, 2013). Graduates could only read a few words per minute. On average, students were not able to correctly answer any of the questions in the reading exercise. 2 out of 5 could not read any words; 95% read 20 words or less. Reading instruction had statistically significant improvement, but the performance was still low.

Figures 21-22. Angola and Liberia correct words per minute



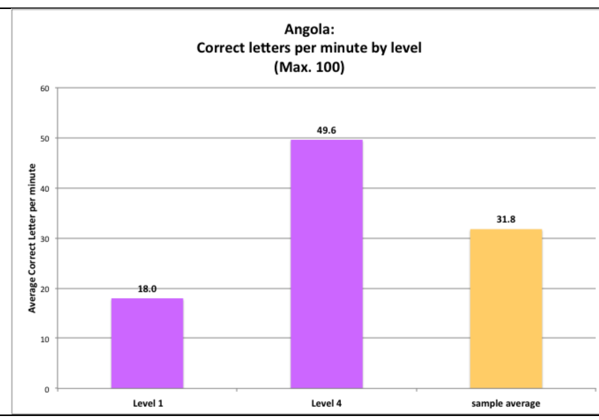


Table 3. Number of comprehension questions answered correctly by neoliterates

	N. of questions	Liberia	Angola
Reading	3	0.6	0.67
Listening	5	2.4	2.6

A donor-financed literacy program in **Afghanistan** taught women in accordance with the government literacy curriculum, which specifies 2.5 hours instruction per day for nine months. The curriculum was based on Freirean philosophy, promoted by the UNESCO Institute for Lifelong

Learning. A page from the textbook shows many large pictures and little text. The method expects learners to memorize letter combinations on the basis of pictures they see. However research does not support this theory. Furthermore, such textbooks give limited opportunities for practice to speed up reading.

Towards the end of the course in 2019, one class was informally tested for fluency. Results show a clear age-related pattern; the best performers are 16-17 year olds, and speed decreases past age 20. Certainly there are individual differences. But in this incidental dataset, the correlation between age and words per minute is -0.74.

Table 4. A class of Dari neoliterates, words per minute by age

Figure 23. A page of a textbook

Student no.	Age	Words per minute
1	16	81
2	16	68
3	16	117
4	16	50
5	16	53
6	17	60
7	17	55

8	18	64
9	18	34
10	19	61
11	20	62
12	20	84
13	20	47
14	25	38
15	25	40
16	30	30
17	30	35
18	35	13
19	40	20
20	45	15

Monitoring and data collection difficulties

The UNESCO Institute for Lifelong Learning tries to collect data from various programs and follow up, but the task has been difficult. Haphazard implementation, volunteer teachers, and spotty supervision have made monitoring and data collection difficult. Many programs have little to offer besides promises and hopes.

The available data are often uninterpretable. A World Bank project in Morocco, for example, merely monitored population changes in self-reporting about literacy. Some programs that have been hailed as innovative show poor recall. One program in Pakistan graduates about 95% of the learners, but few know can then enter formal schools.

Literacy programs should generate words per minute and comprehension percentages, as with children. Hardly any of them do so. Programs with more scientific components should also monitor event-related potentials through electrode caps on the skull. Then improvements can be detected from a baseline.

Survey questions to gauge literacy. A number of international agencies and data collection initiatives monitor adult literacy incidence. Quandaries arise on how to detect literacy easily and quick. In addition to schooling data or to reading 1-2 sentences, persons could be asked questions that are indicative of automaticity, for example:

- When you watch TV, can you read subtitles or ads?
- If you look quickly at a newspaper, can you read the head titles?
- When you pass by stores do you usually read the store signs without trying?

There is nothing more cynical than empowerment visions and graduation ceremonies for women who are still illiterate. Data have been sometimes manipulated for reasons of embarrassment, but the research in this paper suggests factors beyond the implementers' control. The following section formulates more specific hypotheses.

Chapter 11: Where are the neoliterate adult dyslexia deficits located? Some hypotheses

The problem identified in the foregoing research findings might be likened to internet routers that somehow do not transmit a wifi signal. The power is on, the settings are correct, but a frayed wire somewhere in the phone-line circuits compromises the signal. Where is the problem and what does it consist of?

And is the neoliterate adult dyslexia the same phenomenon in educated and unschooled adults? If both categories share some visual problems, the difficulty could arise in brain networks that function similarly in these populations. This may suggest a developmental deficit that occurs early in the visual system.

The reported deficits and related research suggest changes in one or more neuronal groups that happen during adolescence and have subtle, but ultimately profound, effects on reading fluency and functioning in a society that uses a certain script. Where could these be? Some very preliminary and tentative areas for exploration are as follows.

The dorsal pathway?

Children start reading by relying on the dorsal pathway. As they attain fluency, processing shifts to the ventral pathway that offers a direct print-to-meaning connection (Pugh et al., 2000; Rueckl & Seidenberg, 2009; Sandak et al., 2012). The dorsal pathway locates the symbols in space and sequence, and it seems related to phonological activation, that is letter-by-letter reading.
The dorsal stream relies on the right parietal lobe, which is critical in visual working memory. It permits the maintenance of object identities and their locations across brief delays, such as those accompanying eye movements. It also permits recall of the spatial coordinates. The parietal lobe, perhaps infero-parietal region, may have a general role in remembering various types of visual information, mainly motor spatial attention and spatial memory (Berryhill & Olson, 2008). One possibility is a restriction of visual short term memory (Pelli, Farell and Moore, 2003), so that fewer features are identified at one time after a certain age. At the right posterior parietal region, visual short-term memory resides and acts as a bottleneck. This cognitive resource declines with aging, particularly among older adults (Wiegand, Lauritzer, Osten et al., 2017).

Evidence for difficulties in the dorsal pathway may be the inability to keep letters in a row and to identify some earlier than others. Scripts that have symbols above and below letters, or that are nonlinear, create special problems. A Hindi matra of o vs. e can be easily misread, particularly within a word; e.g., the e sign on top seems visually unstable; खोलना vs. खेलना.

Feature integration deficits also seem related to dorsal stream functions. Goldstone (1998) had stated that children “unitize”, that is they make single units from multiple letters. A deficit in learning from statistical regularities (Sigurdardottir et al., 2017) suggests a problem. The ventral path may be available but not easily used. This also seems to be the case with some dyslexic children.

The empirical evidence presented here suggests that adult learners may be trapped in the dorsal stream. Like adult dyslexics, neoliterates must rely more on the semantic properties of morphemes to make sense of the text (Cavalli, Colé, Pattamandilok et al. 2017). However, the dorsal stream is long. The problem could lie in one of the several areas involved in statistical learning of letter sequences and distinction as high or low probability before and after age 12 (Janacsek et al., 2012). Can it be pinpointed more precisely?

The early stages of the visual system?

Given that both unschooled and educated neoliterates experience this, the origin could be at an early stage in the visual system, which is not directly influenced by education. An example is the lateral geniculate nucleis and the V1 area of the occipital lobe.[35] V1 operates as part of a network involving the precuneus during the learning of goal-relevant complex visual sequences involving discontinuous associations, which are within the focus of spatial attention (Clive, Mallik, Caballero-Gaudes et al., 2018). This area is activated by spatial cognition tasks, episodic memories, and is heavily implicated in both spatial and object-based forms of contextual/predictive processing and associative learning in scene perception (Clive, Mallik, Caballero-Gaudes et al., 2018). Also relevant may be the clustered "islands" of V4 neurons that preserve visual acuity and process local-global features along the object-processing hierarchy (Lu, Yin, Chen et al., 2018).

The Thalamus?

Another area is the thalamus; unschooled learners show thalamus activation (Skeide et al. 2017); circuits. A critical area may lie between the thalamus and along the dorsal path, including the input neurons from the thalamus to the parietal cortex.

The spatial attention network?

The culprit could also be in the spatial attention network of the parietal cortex. The parietal cortex is involved in spatial attention and binds features into larger shapes when the features are shown simultaneously at different locations (as would be in Arabic; Shafritz, Gore, & Marois, 2008). This is one more reason why the spatial arrangement of words suggests the involvement of the dorsal path.

[35] The lateral geniculate nuclei transmit information that includes spatial frequencies received by the V1 area (Frazor, Mante et al., 2005). Neoliterate adults seem to have difficulties with high spatial frequencies.

The ventral occipitotemporal cortex?

Yet another "suspect" area may be the ventral occipitotemporal cortex that integrates visual input with higher-order experiences. Adult neoliterates can make word predictions but with high error rates and effort (Price & Devlin, 2003; 2011). Perhaps some circuits involved in this process transmit information too slowly or inefficiently after a certain age (see dorsal and ventral streams). Script features may just not arrive fast enough to be perceived as entities in the visual word form area.

Observation of learners' errors offers some insights. In 2005, for example one woman who had attended literacy class in Indonesia recognized an initial k, recalled multiple words starting with k, and composed a sentence completely unrelated to the text. This may suggest coupling between the parietal and temporal lobe structures, but with very little scriptural input flowing through.

Furthermore, temporoparietal connectivity may develop deficits. It uniquely predicts reading performance (Lee, Booth, Chou, 2016), predicting change from childhood to adolescence. The left posterior middle temporal gyrus is an important node in the semantic network. The inferior parietal lobule is involved in visuospatial processing. On the other hand, the connection with the inferior parietal lobule should have been established in childhood in the educated readers. So the problem should not involve this connection. However, phase coupling rather than connections may matter.

Chapter 12: Conclusions and implications

This extensive research review points to multiple areas that could elucidate the fluency difficulties of those who try to learn a new script in adulthood. The research highlights some issues that are relevant to policy and instruction:

The difficulty is perceptual rather than linguistic. People may attain and maintain sophisticated knowledge of a language, yet be forced into laborious letter-by-letter reading for years. To educated adults, the reading experience does not at all resemble the experience in a childhood script. The constant conscious effort to decode and retain sufficient material into working memory causes fatigue and avoidance.[36]

The suspected problem seems to lie somewhere along **the dorsal stream**. It may involve V1, V4 areas or the parietal cortex. (V4 is involved in pattern formation but is considered part of the ventral path.) A sensitive period may involve declining circuits but also oscillations of brain waves that are out of sync with the neuronal groups where a signal is to be transmitted (Tzvi, Verleger, Muente et al., 2016; Voytek et al., 2010). Perineuronal nets[37] may also be involved, that regulate plasticity in the visual cortex as well as in learning and memory circuits (Shen, 2018).

The dorsal stream involvement is suggested by the difficulty in integrating features, keeping letters on the same line, and/or selective neglect of features in various configurations. Fewer features than are needed are detected and retained in visual working memory, resulting in very inefficient reading, with many mistakes. The responses inevitably affect the ventral stream, which then does not receive input quickly and predictably enough. Thus, parallel processing and the direct print-to-meaning function are not activated, and the neoliterates must decode subvocally. Scanning text is difficult and requires larger shapes that can be easily compared. Letters with distinct shapes are identified faster than others.

Visual statistical learning may build an efficient object recognition system, with neural mechanisms that extract useful feature combinations based on simpler features that tend to appear together (e.g. word fragments). Somehow this object recognition system is not efficiently employed by adult neoliterates. Visual short-term memory seems to play an important role. It may compromise statistical learning because all the minimally necessary features are not recognized. This somehow impedes entry into implicit memory, either through practice and, in relation to increasingly larger chunks, through unintentional implicit learning. The unspecified neurological difficulties mean that the letter and word shapes remain partly in explicit memory and are vulnerable to forgetting.

[36] Frontal lobe neurons are used for general functions, require more energy than neurons in other areas; concentrated work using the frontal cortex results in mental exhaustion (Sapolsky, 2017; Larson, Haier, LaCasse et al. 1995).

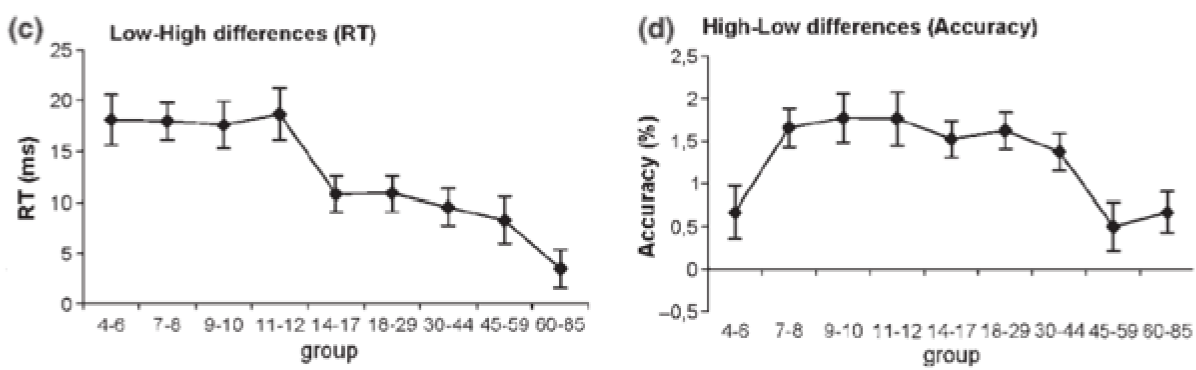
[37] Perineuronal nets are lattice-like elements that wrap around certain neurons. Patterns of holes in their structure may hold up very long-term memory. Degrading perineuronal nets and may return neurons to a younger, more malleable or "plastic" state (Shen, 2018).

At a neurocognitive level, the deficit is subtle. Perhaps it has escaped detection because studies probing perceptual learning variables have used relatively simple stimuli. The difficulties may emerge with more challenging tasks. Reading demands instant response to hundreds of letters in configurations of various word sizes. There are few tasks that demand a similar degree of minute distinctions in milliseconds, notably air traffic control and music notation.

A sensitive period, or difficulty in coupling brainwaves, could create visual deficits that start during adolescence and become progressively worse in adulthood. It is tempting to attribute the difficulties to the slowdown that takes place in aging. However, the problem becomes significant in young adulthood, when processing speed is near its highest peak (Hartshorne & Germine, 2015).

Interviews with educated neoliterates suggest that the problem becomes significant by around the age of 18 and deteriorates thereafter. No data are available to suggest a trajectory of deterioration. One hypothesis would be to follow the Janacsek et al (2012) trajectory in detecting high vs. low probability triplets of shapes. This would suggest a gradual deterioration of statistical learning, leading to increasingly serious errors and omissions.

Figures 24-25. Reaction time and accuracy in detecting frequent and rare shapes by age



Clearly, some people perform better than others, as suggested by perceptual learning research (Kóbor, Tacács, & Nemeth, 2017; Kalra 2015; Xue et al., 2006). Larger visuospatial memory may help, and some people may have better genetic connectivity among various regions. A slightly larger VWFA, and/or an enhanced ability to recognize faces, may compensate for upstream deficits. Exceptional executive functions and perseverance may also help maintain effort (Horowitz-Kraus & Hutton, 2015). But it seems that even people with such capacities would perform far below the criterion needed for fluent and effortless performance.

Dyslexia and alexia may help define adult deficits. Dyslexics have symptoms similar to adult neoliterates, but they also have early neurological deficits that, at least, educated learners do not share. The alexia symptoms are also relevant, as well as those of dissociative agnosia. In both cases, research points to areas of damage, but cannot clearly point to tracts of neurons that in some way affect fluency between that point and the retina of the eyes. Actually NAD may in some ways facilitate understanding and treatments for dyslexia and alexia.

Hopefully the detail and evidence presented in this document may arouse interest. Those who doubt the NAD hypothesis should try to learn to read a new script and observe how well they can do it.

The qualitative information available on educated readers (and quantitative data on unschooled neoliterates) who have sought to learn to read point to the possibility that **we all become dyslexic for new scripts by age 19 or so**. The implication is bizarre: humans spend most of their lives in a state of dyslexia. Dyslexia researchers are likely themselves dyslexic, even when they try to learn a partly known script, such as Greek or Cyrillic. If this hypothesis is as expected, then dyslexia (for various reasons) is the natural state of our brain in most of our lives, except for a narrow window that starts closing in mid-adolescence. [38]

[38] The research also elucidates archeological questions regarding script dissemination in the antiquity. At a time of scarce practice texts and systematic instruction those who could learn with the fewest examples had an advantage. They had to be children or early adolescents. Scripts such as Cuneiform that involved minute perceptual distinctions would not be easily learned by adults. It is likely that children or teenagers helped transfer alphabets across countries and established new uses. For example, the Phoenician script transferred into Greece and that in turn transferred to Italy. Illiterate adults would have found it hard to retain, reproduce, and adapt a new set of symbols.

Chapter 13: Instructional and policy implications

Back to teaching the unschooled illiterates… Clearly the global policy challenge of imparting literacy, especially to adult illiterates, is onerous.

Unschooled illiterates face multiple challenges. Research suggests that, as a result of being unschooled earlier in life, adult illiterates have shorter working memory, phonological awareness deficits, and language processing limitations. They are often poor and from rural populations. Social disadvantage may reduce the time and attention available for instruction. It is difficult for the malnourished to concentrate and even more so for illiterate women who may have a baby tugging at their breast in literacy class. Given the current state of knowledge, hundreds of practice hours are needed to automatize a script, and learners may possess neither the time nor the materials.

Figure 26. Literacy class of senior citizens in Nepal

Figure 27. Literacy class in Senegal (UNESCO)

The neurocognitive difficulties are exacerbated by inefficient reading methods. Colleges of education worldwide present literacy from humanistic and philosophical viewpoints. Government and donor policy documents make references to "multiple literacies" or digital literacy, and disregard the necessary early stages leading to effortless reading.[39] Literacy specialists are often linguists, so language and meaning may take precedence over perceptual learning. Highly educated and automatic readers tend to think of literacy as easy, so many people present themselves as experts. The result has been extensive training and financing of programs that perform poorly. Furthermore, the neurocognitively-based reading variables appear narrow and incredulous.

Ignorance of the essential variables creates many unintended inefficiencies. Literacy curricula are often loaded with empowerment concepts such as numeracy, income generation activities,

[39] It is even difficult to define literacy. Around 1967 UNESCO documents defined literacy in terms of letter knowledge and ability to write a sentence. However, updated definitions should include the need for automaticity and ability to read instantly letters rendered in the small and dense fonts used by automatic readers.

rights education and microfinance,. These are certainly important, but they use up time needed for reading practice. Furthermore, complicated literacy instruction requires extensive training of poorly paid instructors who may be expected to plan lessons, do administrative tasks, and test students while often being poorly educated themselves. Logistics may take precedence over instruction and practice. Reading textbooks may also be hard to procure, so organizations may decide to teach without them. Lack of practice leads, at best, to halting reading and all but guarantees a relapse into illiteracy within a few weeks of course completion.

Thus neoliterate adult dyslexia has important policy implications for formal education. **Children must acquire fluency by mid-adolescence.** If they never attend school or drop out illiterate, they may suffer from lifelong exclusion from the knowledge provided through print.

Figure 14.1, from the *SACMEQ at a Glance* series of the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SACMEQ), shows the literacy levels for each of the pilot countries at Grade 6 (Spaull, 2012a).

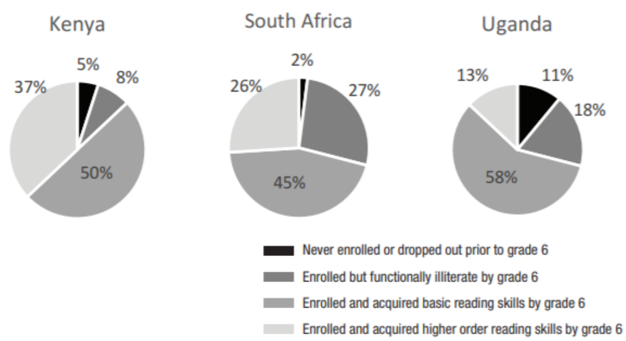


Figure 14.1: SACMEQ III (2007) literacy results in the three pilot countries of the African Storybook initiative.

Figure 28. Miao et al., 2016

NAD also has multiple implications for educated people. Worldwide many religious and immigrant communities need to teach the younger generations scripts different from the ones taught in schools. Indians, Arabs, Greeks, Russians, Armenians, Cambodians, Thais and others ought to ensure their children become fluent readers of relevant scripts by mid-adolescence. At that age, reading instruction and practice may take a back seat to sports and social media. And although adults may be able to learn to speak a language at any age, if it uses a different script they may forever be effortful readers. However, reading practice in childhood may at least enable middle-aged people to deal with important written documents such as parental wills, legal documents, and old letters.

Similarly, university students who want to learn languages with different scripts must take action early. Eighteen year-olds who enroll for an Arabic course may have a significant reading advantage over 25-year olds. Government Ministries that train diplomats in languages with different alphabets and scripts must similarly become very conscious of this issue.

Chapter 14: Potential Remedies for Performance Improvement

Neuroscientific and perceptual learning research point to multiple "low-level" variables that are prerequisite to effective and meaningful reading. These include accurate perception, attention to relevant features, optimal size and spacing parameters, statistical computations and feature integration. Hundreds of practice hours are needed to streamline the output of the brain circuits that carry the various signals. The same process applies for children, but they attain automaticity much earlier (Abadzi, 2017). Obviously transparent orthographies are simplest to teach and practice. Complex orthographies, such as English or Khmer, also require instruction in the various rules and exemplars.

These variables involve people's implicit memory, that unconscious; policymakers or donor staff therefore do not easily think about them. People in particular who live in higher-income countries tend to ignore perceptual learning variables. They leapfrog instead onto language and meaningful texts. Furthermore theories exist that neoliterates can read if they have sufficient motivation, engage in social learning, or get help from families. There is no research to suggest that social learning or grit will speed up perceptual learning sufficiently. These biases towards explicit memory and commonsense ideas impede research and program design to help adults attain fluency.

What can be done to enhance the efficiency of instruction and practice towards automaticity? Reading instruction must build and optimize each of the tasks that seem to affect the dorsal stream. This suggests adopting approaches that optimize visual perceptual processes first, and matching them with sounds, until they are automatized and take only a few milliseconds to process.

In principle a prototype program could be developed drawing on the most feasible solutions, but piloting is needed for effectiveness as well as for contextual logistics.

Research-based recommendations include:

- Intensive courses involving *extensive perceptual learning practice*, longer than 30 minutes at a time, with short breaks (Little, Zhang, & Wright, 2017). Initial intensive engagement may help neurons "fire and wire together" faster than shorter periods subject to forgetting. This may be one reason why intensive courses have better outcomes (Kurvers, 2007, 2014). Learners must spend most class time in individual practice and do homework if possible.

- Teaching and practicing *letters, one by one* (Pelli et al., 2006). To deal with practice volume, every learner should have a textbook with perhaps 10,000 words of text in spaced and large letters to practice from. The textbook should have multiple trials of every possible combinations, with at least 3000 to perhaps a million repetitions, until reaction time is optimised and no longer improves (Suchow and Pelli, 2013).

- Ensuring characters are *large and spaced*, then gradually decreasing in size over time. The relevant parameters are unknown, but it is known that crowding significantly and adversely affects older adults. Letter size and spacing may be experientially determined until relevant research is done. One example is the Nepalese "pahilo paila" textbook. (Gautam, 2018 of Ageing Nepal). [40]

र रा	रेल केर नेल लेक लेन नोले रेना केरा नाके केरि रोके केर् काने किने लिने राले काले
Figure 29. Pages from the Nepali Pahilo Paila; large and spaced letters taught one by one	Figure 30. Pahilo Paila. Optimization of the pages for practice using large and spaced letters

- *Repeated reading practice to increase speed*. Learners could repeatedly read a text until they attain a speed of 80 words per minute on that text (LaBerge & Samuels, 1974). This speed may be arbitrary, but it corresponds to relatively fluent performance. It would be important to study how many repetitions adults need on average to attain 80 words per minute. To focus first graders' attention in better off income countries, powerpoint projectors help, but in poorer countries, large letters on blackboard help. Practicing within 3.5 hours after class may facilitate consolidation (Bang et al., 2018).

[40] In Nepal, a course for senior citizens over age 60 was held for 4 months. At the end, the learners read roughly 17 Devanagari characters per minute, only 66% correct (Gautam, 2017). A perceptual learning approach was instituted, and learners read on average 39-42 letters and 12-15 words per minute. Still, the learners could not deal with lengthy texts. The textbook used large and spaced letters, but it is unclear how well graduates would read the small, dense, and calligraphic letters found in street signs.

- *Using mnemonics and memorization techniques* to facilitate long-term consolidation, at least in explicit memory. These would include rhymes if relevant, body postures, allusion to shapes in the environment etc. Perceptual learning can take place when stimuli are imagined rather than presented, thus mental imagery training may aid perceptual learning (Tartaglia, Bamert, Herzog, & Mast, 2009). Adults may be led to visualization exercises and be asked to visualize letters and words after class.

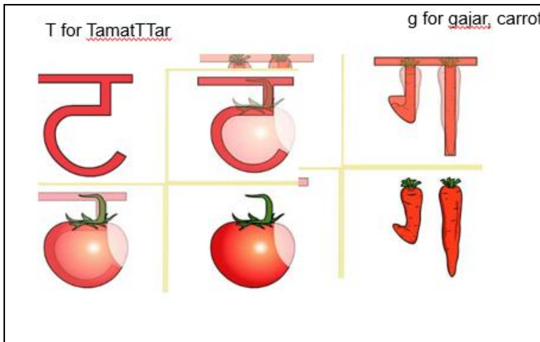
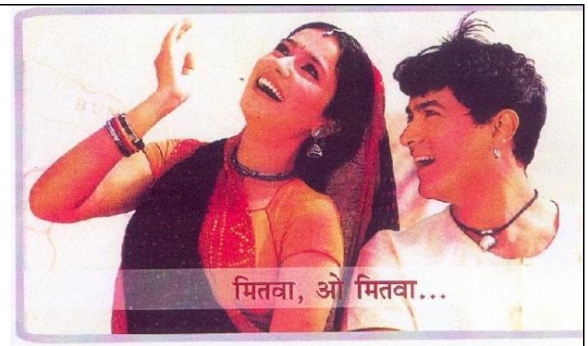
	

Figure 31. From taraaksar.com	Figure 32. Same language subtitling for faster readers

- Multisensory methods, such as *touching letters in relief*, help adults connect shapes and sounds more than just visual (Fredembach, de Boisferon, & Gentaz, 2009). The addition of haptic exploration of visual novel stimuli seems to help adults to associate more shapes and sounds, than does visual exploration only. The research does not clarify if automaticity and reaction time are speeded up.

- *Focusing on stimuli for extended periods*. Earlier research found that encoding is facilitated if it pays attention to a chunk of information for eight seconds (Simon, 1986). Looking at letters or words attentively for several seconds is more likely to result in encoding than briefly glancing at them. The learner could simultaneously pronounce the combination and write it on paper or trace by finger.

- Statistical learning could be enhanced in various ways, perhaps focusing on high probability occurrences. For example, statistical learning can be enhanced by showing one letter in the middle of the screen and asking learners to pay *attention to certain color-coded features* (Turk-Browne, Jungé & Scholl, 2005 in Sigurdardottir et al., 2018). Making letters jiggle or move across the screen, also improved statistical learning. It may be useful for visually complex alphabets, such as Arabic.

- *Extensive writing*, including copying and dictation. Writing is time-consuming but the writing network may enhance shape recall. Adults should form letters while pronouncing the sounds in hopes of permanent linkage.

- *Facilitating feature integration* by guiding students to letter locations is important for discrimination. Training in letters that may be confused with each other, or are slow to be identified, might improve detection. Of potential use would be to rank the letters of specific scripts through a method such as bubbles (Fiset, Blais, Arguin et al., 2009) and then to offer computerized practice in guiding attention. This might speed up feature integration. The method could also be used to speed up the reading of handwriting. Similar goals might be accomplished by specifically directing attention to letter shapes by including task-irrelevant exogenous cues (Carrasco and Szpiro, 2015; Szpiro, Wright, & Carrasco, 2014).

- *Using computer media*: Many techniques and methods are best delivered through computers, cellphones and tablets. Computerized instruction is mainly feasible for educated people or illiterate immigrants in well-to-do countries. Poor countries must rely on paper. Software could track performance and challenge learners, through engaging scenarios and graduated targets, to read increasingly faster – until they attain 60 words per minute. (Instruction of sophisticated learners could take place by skype or other media.) For example: The graphogame app, developed in over 30 languages by the University of Jyväskylä in Finland, has been used by children who, after playing the game for four to five hours over several weeks, significantly increased their spelling skills (Jere-Folotiya, Chansa-Kabli, Yalukanda et al., 2014).

- *Certain games*. A game created by the Behavioral Science Institute in the Netherlands significantly improved reading fluency and accuracy (Verhoeven & Keuning, 2018).

Potential interventions derived from dyslexia and brain injury research include:

- *Preparing the dorsal system for reading* (Gori & Facoetti, 2013) through exercises to detect coherent dots motion. The ability to reduce the magnocellular–dorsal pathway deficits and the increase in their selective attention skills could improve the letter string parsing and/or cross-modal integration that reading requires. Such an exercise might specifically benefit unschooled illiterates.

- *Practice* to *perceive moving small objects in low-contrast lighting conditions*. In principle, this would help learners to detect small items that they are not used to seeing in real life.[41] For example, learners could practice detecting dots above or below characters in small fonts faster and more accurately. One app that does this is Ultimeye (Deveau & Seitz, 2014).

- *Fast action videogames* may evoke emotions and thus consolidate shapes into implicit memory. These have been found to be effective in changing feature perception and developing shape discrimination (Bavelier, Levi, Li, Dan, & Hensch, 2010).

[41] After training, reading acuity improved an average of 13%; reading speed improved an average of 13% ($p = 0.0004$), moving from a pre training mean value of 240 words per minute to a post training value of 271 words per minute However, critical print size did not improve after training (Deveau & Seitz, 2014).

- *Stimulating the vagus nerve* may speed up consolidation of individual letters (Centanni, in preparation). Also brief direct stimulation in visual or other areas could be feasible; for example, brief direct stimulation of the amygdala for patients with implanted electrodes improves memory of visual images (Inman, Manns, Bijanski et al., 2017).

- *Stimulating the motor cortex using wearable devices* to improve connectivity between the motor cortex and muscle groups for various sports, it could be tried with perceptual tasks. This is one of several transcranial direct current stimulation applications (Krause, Zanos, Csorba et al., 2017; Herpich, Melnick, Agosta et al., 2019).

- *Using ultrasound waves directed at the brain to boost sensory performance* (research by Roi Cohen Kadosh, University of Oxford). Virginia Tech Carilion Research Institute scientists research ultrasound neuromodulation techniques in achieving spatial resolution.

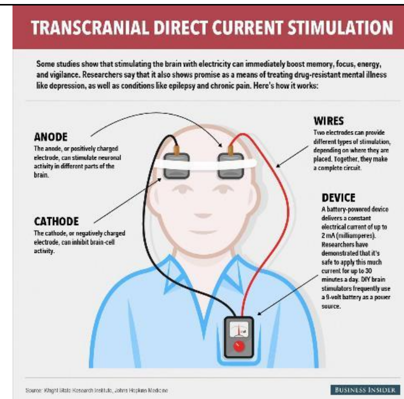
- *Auditory practice of the same skill* to continue learning (Wright, Sabin, Zhang et al., 2010). An auditory task was trained for 20 minutes and was combined with 20 minutes of work on an unrelated puzzle while students continued to hear it. Learning was comparable to practicing for 40 minutes. The tasks should be separated by no more than 15 minutes, and evidence of metaplasticity disappeared if the sessions were separated by four hours. The challenge would be to develop feasible solutions involving letters or texts.

- *Exercising 4 hours after learning* may facilitate perceptual learning with a minimal number of trials and transfer to untrained directions without requiring sleep. (The task involved Chevrons; Aberg, Tartaglia, & Herzog, 2009). For a task of visual and spatial learning, those who exercised 4 hours after learning recognized and recreated the picture locations most accurately. Their brain activity was subtly different, too, showing a more consistent pattern of neural activity (van Dongen, Kersten, Wagner et al., 2016). The reasonable intensity and routines are unclear. The role of sleep for consolidation of implicit memory is also ambivalent.

- *Improving attention to the specific stimuli by moving text* can be used to improve text reading in patients with hemianopic alexia. The "Read-Right" method improved patients' reading speeds by 39% on average, after 15 hours of cumulative practice (Ong, Brown, Plant et al., 2012).

Figure 33. Moving text in stationary window

- *Using reading pens*, which are available in many languages, to highlight text aloud. Some organizations working with illiterates use them to facilitate their information processing. The device may be also used for reading practice.

	
Figure 34. Device reads text where the finger is[42]	Figure 35. Transcranial direct current stimulation[43]

- *Learning drugs* have been used in some research, such as valproate (Gervain, Vines, Chen et al. 2013) or dopenezil (research by Takao Hensch in 2014). These could potentially reverse some sensitive periods. Similarly, drugs prolonging sensitive periods in the auditory thalamus could inspire research on visual perceptual learning. However, drugs are not a solution for the poor or for country-level interventions. Drugs which make the brain more malleable for new experiences may also increase the effects of emotional stressors, as happens to children, particularly females. [44]

- *Essential fatty acids* in the past had shown some effectiveness in improving children's reading skills. In children 3 months of omega 3/6 treatment improved reading ability - specifically the clinically relevant 'phonologic decoding time' and 'visual analysis time', particularly in children with attention problems showed treatment benefits. (Johnson, Fransson, Östlund et al, 2016). These substances may have utility for adult residents of poor countries.

- Use of *artificial intelligence algorithms* to gauge the letter features and combinations that adult illiterates find easiest and hardest in various writing systems. Some are likely to be idiosyncratic, but others are likely to be systematic and related to the visual system. Tailored practice could be delivered by computer to learners or be used to optimize printed textbooks. Research is ongoing and results are mixed (Bashivan, Kar, & DiCarlo, 2019) but they suggest that single neurons could be trained to recognize letters and

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[42] http://www.iflscience.com/health-and-medicine/new-finger-device-reads-books-blind

[43] http://www.businessinsider.com/brain-hacking-will-make-us-smarter-and-more-productive-2014-7

[44] Nafissa Ismail, U. Ottawa; also mentioned in Encyclopedia of Mind Enhancing Foods, Drugs and Nutritional Substances, 2d ed. (David W. Group, Ed.), 2015.
https://theconversation.com/the-science-drugs-and-tech-pushing-our-brains-to-new-limits-65281

features as a compensation to a dysfunction in the adults' perceptual learning mechanisms.

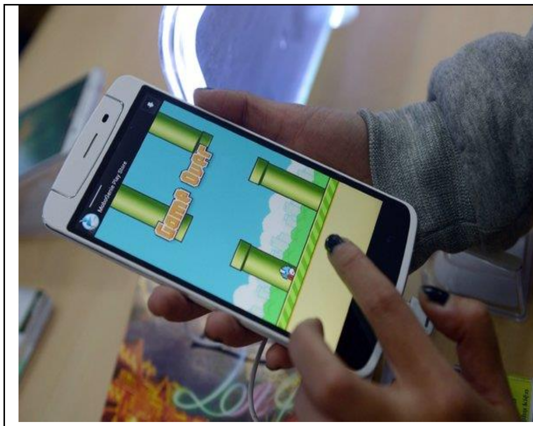

Figure 36. Fast-action videogames (Bavelier and others)

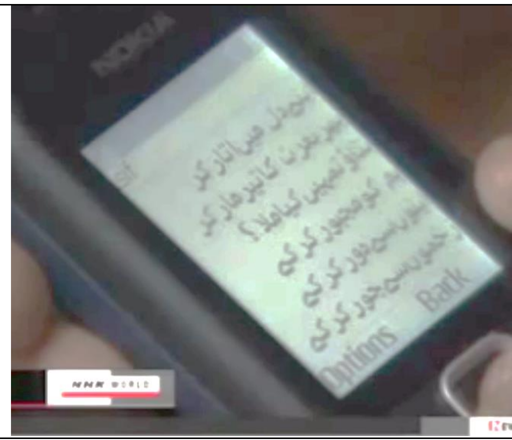

Figure 37. Cellphone messages to adolescent neoliterates (UNESCO – Bangkok pilot)

Specifically for illiterate adolescents, it may be useful to combine some methods. They will clearly benefit from letter-by-letter instruction, but their statistical learning system may already be inefficient. They could benefit from computerized exercises to prepare the dorsal pathway for letter detection. Also adolescents may have a narrow window of intervention.

New paradigms are published frequently. Potential treatments would include hints from alexia and dyslexia treatments, such as multichannel inputs, increasing the contrast between letters and background by putting computer-generated frames around each word read, or slow *same-language subtitling* with words shaded when they are heard. Thousands of trials in developing feature integration may make a difference, probably through computers rather than print. The speed may be too fast for many beginners, but video and audio tracks may be slowed down.[45] *Virtual reality* may also have some uses.

[45] For example, the "Little music player" in Arabic (Bookbox.com, 2004) lasts 5:33 minutes and has about 290 words, yielding a speed of about 52 words per minute. Readers able to follow at this speed are largely reading automatically. It's still a minimal speed, and learners can improve through this method. It is therefore useful.

Chapter 15: An urgent need for research

Overall, studying literacy acquisition among literate and illiterate adults is an area of fertile research related to brain plasticity. Research is urgently needed to have any hope of transforming illiterates into fluent readers. The lack of quantitative data impedes the research. To speed up progress and attain automaticity in adulthood, it would help significantly to know the precise brain areas involved in the problem. Hopefully some scholars may become interested.

Sometimes it is possible to tailor educational or computerized stimulation exercises. A number of such treatments have been proposed for dyslexics or alexics, and it may be useful to pilot these for adult learners. Trials should be conducted on some of the possible methods discussed in this section. There is a need to prove these concepts and assess effect size. Reading research in high-income countries uses **event-related potentials to monitor automaticity**, and donors should learn enough about this and other feasible technologies.

Research should explore means to optimize reading for adults. Even if automaticity is not attainable, one goal would be to bring them to a stage of fluency where they can read to themselves aloud.

Behavioral research is certainly necessary, such as measures of words and letters per minute that adults can read under certain circumstances. But more precise methods are also needed, such as eye tracking, electrophysiology, and neuroimaging techniques to compare the skills of educated adults reading in their native scripts with performance in scripts that they read haltingly. It is expected that differences in processing paths would be detected, and the riddle regarding the origin of the problem would be resolved. It would then be easier to focus on means to improve performance. For example, researchers could apply the protocols of Žarić, Correia et al. 2016, which used EEG to show altered visual word processing in dyslexic children. It is important to study populations of various languages, because most studies use English readers and the Latin script.

One way to compare performance in adult versus child literates and to eliminate language proficiency would be to teach Hindi and Urdu speakers each other's script. Universities have many students from such populations who could volunteer. Outcomes could be compared through behavioral measures as well as neuroimaging techniques.

Some of the many applied research questions to be answered include:

- How do reading rates increase as a function of practice hours? It is unknown how long adults must practice, since implicit memory somehow does not easily form from practice. Consolidation timeframes must be explored. It would be also important to explore the top speeds that adult learners can attain given various amounts of practice. Can late literates attain 250 words per minute, for example?

- How is face recognition relevant to reading? Prima facie, the relationship seems limited to the amount of face-specific resources, or parts, or when faces are shown upside down (Thoma, 2014).[46] The effects of the VWFA anatomy and changes in adolescence could be explored.

- How many hours of practice would neoliterates need to transition to fluent reading of typical text? Investigating the habituation trends to small and dense letters typically used by fluent readers.

- Examination of systematic and random errors in various languages and scripts, particularly considering high and low statistical probability combinations.

- What is the optimal amount of writing that would consolidate a memory of letter values? Similarly how useful are mnemonics and shape movements towards this goal?

- How does the top reading speed that people can develop vary by age of literacy acquisition? If students, for example, become literate at age 15 rather than the usual age of 6, will age limit the top speed they can develop?

- If effective literacy acquisition programs are used, at what rate does the VWFA become activated in adults learning a new script? How does the activation intensity relate to words per minute read in various languages and scripts?

- How important is the advantage of language knowledge in automaticity acquisition, given the apparent importance of perceptual factors?

- Unschooled adults typically are native readers and may have better language command than educated foreigners learning a new script. If both populations receive effective literacy programs, what differences in speed and sustainability of literacy will be found?

- Given an effective instructional method, how many hours of instruction would an average child require in a particular language to attain 60 words per minute, compared to an average unschooled adult?

- Reading acquisition in childhood may be subject to forgetting, as is the case with language attrition. Children up to about age 8 after separating from their speakers may rapidly forget the languages they spoke. Interviews with informants suggest similar experiences with scripts. Three informants reported that they later forgot alphabetsthat they read as 6-10 year olds. Two other males, who had gone to school in Greece until age 15 could read haltingly in their 50s. It would be useful to study whether formerly automatized

[46] Tests useful for research could include the Mooney Face Test, the Glasgow Face Matching Test, the Cambridge Face Memory Test, and the Composite Face Test (e.g., those listed in Verhallen et al., 2014).

scripts can be recuperated and, also, what the top reading speed can be under conditions of intense practice.

- Given the linkages between motor and perceptual skills, it is possible that writing speed, accuracy and acceptable shape could predict reading speed. A model could be developed to predict performance on the basis of these variables.

If current policies and methods are not updated as a result of research, adult performance will continue to be deficient.

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