Part II

How Brain Imaging has Contributed to

the explanation of how readers are able to read words as easily and quickly as they hear and understand speech.

The continual unraveling of the mystery

What remains to be answered?

If the prior learning of letter/sound connections of a word are firmly in place, strongly rooted in phonemic knowledge and skills (Ehri's theory), the question remains: how is the final action of instant word retrieval accomplished? The complete answer, based on the relationship between reading and speech, was only suggested in Ehri's theoretical explanation. It has been confirmed by brain imaging. The brain will do for reading words what it does for hearing words in speech - once letter/sound learning is accomplished.

This explains why humans are able to read so well. The short answer: Because they can speak.

How is this so? Brian imaging studies inform and confirm that speech enables humans to learn and read an alphabetic language quickly. The ability to read comes from the ability to speak and listen. What is used in the brain for speech can be applied to reading if L/S are firmly in place. This understanding can lead to a better understand of what needs to be taught, especially at the beginning, and how and what can go wrong in the process, characterized as developmental dyslexia.

Review

After examining the behavioral studies of Ehri and others about the mystery of reading words, what remains to be explained on both levels of the mystery?

A phonological theory of reading words needs to be able to explain more than **what makes it possible** to retrieve words in oral memory, from the letter/sound bonding. **It must also account for what performs the quick retrieval itself, at the epicenter**, once the connections are firmly set up to make this possible. The retrieval involves the speed of both the searching and the finding of the correct **bundle of phonemes** for each word. **How is this powerful memory and retrieval of words completely explained? How is the involuntary or obligator action explained, once the set-up is in place?** This explanation must also include how and why children are able to "learn to read unfamiliar words so quickly, after very few exposures to the words", [1.] and then, learn the whole foundational base for reading words within 2 to 3 years of their young lives.

Ehri's theory does suggest this deeper explanation by referring to speech but lacks clarity. So, some aspect of the mystery is yet to be solved. The "set-up" part, described by Ehri, concerns what needs to be learned so that the spellings of words can "piggy-back" onto their pronunciations. Perhaps, **if more can be learned about** the connections to speech, the **added force can be identified that explains the full act of reading words, as quickly and easily as hearing speech**. Gough's metaphoric concept of cipher reading, plus added "word knowledge" as needed, seems to imply a need for something more, beyond what the naked eye can observe in experimental studies.

From the start, two level of the mystery has been identified.

At the first level, the theory pertains to the "set-up" and the full **search, find and retrieval,** at the connected epicenter, to the correct word in memory in its spoken form. Experimental research explains the "set-up" by identifying what needs to be learned in order to read words. It then **can only suggest** the remaining action that accounts for the speed and accuracy of the identity and retrieval of words from their storage.

At the second level, the theory pertains to the vast volume of applications needed to read large texts, which may require additional instruction and practice. Yet, the abiity to learn and perform this daunting task, over a relatively short time, **remains miraculous, a part of the mystery**. Is it strictly just a matter of good instruction and practice?

Or, is part of the answer, at both levels, found in some capacity of the human brain that performs speech?

A Basic Foundation for reading includes skills with, and knowledge of, phonological information from speech, at the level of the phonemes. These skills function both as a preparation and an enabler for beginning readers to learn to read. They also continue to have a primary, but hidden or elusive role in advanced reading. (yet to be explained) Phonological information is an intrinsic part of reading words but is hidden from direct observation. This is referred to as a "core phonological model" of reading, **not as whole-word units** but as a result of a specific linkage of small units that make up letter/sound correspondences.

Brain Image research has made it possible to solve these final pieces of the mystery. It can provide a closer look at this hidden aspect of reading words and can confirmed what has been inferred from behavioral experiments. It has added critical information and clarity in the unraveling of the mystery, left partially unanswered by Ehri's work. **It can find the "something more at play" in reading words.** It also gives an improved look at what can go wrong in learning to read that produces the hidden learning disability of dyslexia. Without the understanding of how reading works at the word level, (more clearly revealed by brain imaging), it is not possible to understand the exact nature of what can go wrong, regarding dyslexia. [2.]

What will be learned about the brain from Brain Imaging?

Because the brain already knows how to decoding words in speech, it will do the same thing for reading, once the letter/sound pieces have been put in place and firmly learned.

Overview

The New Science of Brain Imaging will show how the workings of **the brain**, from its innate speech neural mechanism, **provides the final force that enables the accomplished reader to read words as quickly and easily as hearing words**. The final part of the theory that accounts for the hidden finding and retrieving of words in memory can only be found in the neuro-imaging of the brain itself. In Ehri's email of 2014 to the SSR list-serve, she makes clear that the new brain imaging research is consistent with her theory.

> "Although I do not cite the literature on neuro-imaging, it is my understanding that findings are consistent with this theory. I have left it to Shaywitz and others to explain **the neuro-imaging side of the picture**."

The explanation from the "neuro-imaging side of the picture" not only is consistent, it confirms and finishes the theory, left by Ehri, accounting for the final act of reading words.

Ehri suggested that this "**final force**" lies within the innate human capacity for speech and its alphabetic link to printed words. This capability is the result of thousands of years of evolution. **Mark Seidenberg, starts Chapter 2 of his book on the science of reading with this sentence: "We read with our eyes, but the starting point for reading is speech."**[3.] The key words are: "the starting point". At the starting point, reading words gets a "free ride" on the human capacity for speech, making reading words a "parasite" of speech because it "piggy backs" onto speech.

The GPC theory, set forth by Linnea Ehri, provides an essential part of the story: letters in spellings of words attached and bonded to the sounds (phonemes) in memory taken from the pronunciations **make reading words possible**. But there is more. Once made possible, **the brain does the rest**, finding and retrieving the words in storage, the same as it naturally does for speech. It gets a "free ride" on the already built-in mechanism of speech. This final part, left somewhat mysterious and puzzling in the GPC theory, has been made visible from new brain imaging technology. As vital as the GPC theory is, questions remained that needed to be answered for the complete explanation of the phonologically based cipher reading, the kind of quick and easy cipher reading described by Ehri and colleagues. Gough alludes to this "something more" with characterizing the internalization of "cipher reading" as a metaphor.

Fortunately, the **unwitting** historic invention of an alphabetic writing system, which took place over a long period of time,[4.] **by chance happened to link up** and fit neatly, or not so neatly, into place in the brain, within the evolved capacity for spoken language. [5.] An alphabetic writing system, with its bonded letters to the smallest units of, hard to hear, speech sounds in memory, makes the linkage and fit possible. This invention took hundreds of years to develop and to put to use in longer documents. All of the rest of reading is built onto this base. How well it all works, depends on how well the particular alphabetic language represents speech sounds and how well the letter/sound bonding is learned.

The final part of the mystery: the human brain is set up and ready to complete the process.

Ehri and other theorists suggested this possible explanation, made from inferences from their observational studies of reading behavior. From the direction provided by Ehri and others, studies dug even deeper into the hidden phonological aspects of reading at the word level, **using new fMRI brain imaging techniques.** The images were taken during the act of reading and have confirmed, clarified and illuminated this fit between speech and print, and have thus completed the unraveling of the mystery. They identified the "**something more**" that was missing and provided the final explanation for how reading words is performed quickly and easily.

The "something more" that makes word reading seem magical, with the alphabetic connections, is the added **force found within the neurological workings of the brain for speech that completes the process. As it turns out, the human brain, because of its built in capacity for speech, accounts for the speed and the skillful ability, of taking from what is seen in print, to instantly and correctly find and retrieve words, in the oral storage of thousands of words stored in memory. For these functions, the human brain has evolved to contain built-in, pathways and circuits designated to specialize in speech. This specialized mechanism is ready-made to be put to use in cipher sight-word reading, once alphabetic learning has taken hold and provided entrance.**

This final piece of the puzzle required a deeper look into how words are read, beyond the naked eye. This deeper observation was provided by recent brain-image research. The studies have unraveled the remaining part of the story that resolves the full mystery. Even though reading words may still seem miraculous with this explanation, brain image studies provide the further account for the final part of the workings of Ehri's theory. They show how the action of reading words can be done quickly, once the letter/sound links have been set up. They especially indicate how the brain can "miraculously" enable the reader, with additional learning to expand the theory to meet the many complicated demands of reading the massive volume of English words, even with problematic alphabetic spellings.

The relationship of speech and reading

Brain imaging evidence has found that the brain is equipped to do the final part of reading words ***for the reader. Once the letter/sound connections are learned by the reader, the brain is able to read words as quickly as it hears words in speech.*** *This is the "something more" that researchers and scholars have been seeking.*

Because of the human ability to speak, learning to read is made possible. Without an ability to speak, reading an alphabetic language would be very difficult and limiting. This is true because reading is "piggy backed", at the starting point of reading, onto speech through the bonding of letters to the smallest units of speech. This bonding makes it possible to read as easily, quickly and expressively as it is to hear speech. Because of this linkage, whatever mechanism makes speech possible, neurologically, also makes reading possible. Thus to understand reading, some understanding of spoken language is necessary. The speech mechanism in the brain produces the speed and ease of reading a vast number of words, even those with complicated spellings, an action started even within only a few months of schooling. The neurological link to human speech mechanisms supplies the final part of unraveling the mystery, confirmed and understood through brain imaging. [6.]

Prior to brain imaging, behavioral studies were not capable of fully uncovering and explaining the remaining piece of the mystery. Prior to this new source, the specialty of speech could only be inferred, by means of a hypothetical phonological module, as an enabler for reading.[7.] Both Gough and Ehri, among others, projected that the source of the remaining piece of the mystery would be found within the partially hidden realm of phonology in reading's link to neurological speech capabilities.

> "It is in performing this grapho-phonic (letter/sound) analysis for individual words that the **spellings of words penetrate and become attached to reader's knowledge of spoken words in a way that links written language** to the **<u>central mechanism governing spoken language</u>**." [8.] Ehri

Alvin Liberman, of the Haskins Laboratories, (the same place that Shaywitz did much of her earlier studies) makes the same inference, prior brain imaging, from a study of speech. (see Part I)

"Proper use (of an alphabetic writing system) requires that readers **attach the artifacts of the alphabet** to the natural structures of their language, (phonemes) taking care to make the connection at the earliest stage. (**Once this is done**), the **readers get <u>all the rest of the complex processing for free</u>, courtesy of the biological specialization for language that they own simply by virtue of membership in the human race**." [9.] A. Liberman

In Ehri's early experiments, she observed children associating some letters to speech sounds "spontaneously", on their own, without being taught.

> "Because the words or non-words with phonetic spellings, as cues, were learned easier and quicker, even before instruction, it was inferred that connections to the speech sounds were made 'spontaneously', without being taught." [10.]

Did this observation indicated a glimpse of the beginnings, the first signs, of the "obligatory speech activation" in reading words? Did this suggest early signs of a knack for letter/sound linkage? Were they early signs of a natural, neurological knack for a partial latching letters onto sounds by young non-readers, driven by the brain's search for speech sounds in word? Hard to tell. (See Notes on Extension A, Eight Experiments) This observation was made possible through the use of contrived, simplified phonetic spellings of words. It was found that the few letter/sound connections, made spontaneously, assisted some pre-readers in remembering words under experimental conditions. [11.] **These behavioral studies could only suggest what brain image experiments later could verified.** The neurological studies helped to explain how the early **partial** connections could have been spontaneous. They provided an improved, " fine-grained understanding ", of what can be observed with the naked eye.

Brain Imaging Research

The workings of the hypothetical phonological module became confirmed once the new technology made it possible to observe enough of the brain's activity during the act of performing reading related activities. The module is now referred to as the "**universal brain signature**" of proficient reading. [12.] (Ancients believed it was a gift.) As a result of the new technology, research has been able to expand and use a wider range of phonologically-based reading activities that reveal brain activity during reading. This neurological activity could only be previously inferred from behavioral observations of young readers under contrived or experimental conditions.

This is the most important discovery made in the science of reading thus far. It confirms what was inferred and suspected from behavioral studies and then extends this knowledge. The work of the brain accounts for the full action of the instant translation of print into spoken language, with all the subtle nuances and complications that come with an English alphabetic spelling system**.**

The new technology made it possible to directly discover activities in the brain that enable a reader to read words, once the letter/sound links have been learned. It was concluded that the built-in neurological specialty for speech, as a result of human evolution, enables humans to read an alphabetic language system.

Thus, the final answers to the lingering questions are found in the innate human ability for speech, where phonemic information is "obligatory", i.e. involuntary, comes automatically during reading. This is referred to as "**obligatory speech activation**" of phonological activity, i.e., can't be stopped. It ends up being what drives sight-word reading.

> "**Sight-word reading is automatic. It is involuntary. It is part of "obligatory speech activation".** Ehri

> "I believe that in skilled reading lexical access involves **phonemic information obligatorily**. …. **phonemic information is activated <u>during</u> lexical access (links between L/S) as an intrinsic part of the process. This activation of speech codes occurs almost always because speech codes are part of the lexical representation**." **[13.]** Perfetti

This makes reading, at the word level, phonologically driven, done with the ears more that with the eyes. "…any plausible model of reading acquisition must assign phonology a leading role. …Studies suggest that the activation of phonological information **is a ubiquitous feature** of skilled word recognition." **[14.]** Stanovich & Share

According to Shaywitz, the early behavioral research, by Ehri and others, gave the brain image studies direction in terms of **where to look in their inquiries**, rather than leaving them with a general "fishing" expedition.

> "…functional imaging allows the examination of brain function **during performance of cognitive tasks**."
> "…**understanding the phonological basis of reading led neuroscientists to develop neuro-imaging methods** for the study of dyslexia, **based on the phonological theory**. …. Neuro-biological studies have exploited this information **to provide an even more fine-grained understanding** of dyslexia, an understanding at the level of brain function." **[15.]**

Maryanne Wolf, a cognitive neuroscientist from Tufts University, in her book, **<u>Proust and the Squid</u>:** <u>The Story and Science of the Reading Brain</u>, (2007), attributes the most recent improved understanding of reading to come from the " **new science, due to image technology, that enables us to actually 'see' how the brain reads before and after reading.**"

This new science led to both the confirmation and completion of the theory. It led to the explanation of how the brain **…"learns to connect and integrate at rapid-fire speeds what it sees and what it hears to what it knows." All this "with a rapidity that still astounds (mystifies?) researchers." [16.]**

Shaywitz describes **how the technology works**.

> "In principle, functional brain imaging is quite simple. When an individual is asked to perform a discrete cognitive task, **that task places processing demands on particular neural systems** in the brain. To meet those demands requires activation of neural systems **in specific brain regions**, and those changes in neural activity are reflected by **changes in brain metabolic activity**, which in turn are reflected, for example, by **changes in cerebral blood flow** and in the cerebral utilization of metabolic substrates such as glucose."
> "In a typical fMRI (functional MRI) task designed to assess phonological processing in reading, the subject lies in the scanner and **looks up through a prism at tasks presented on a screen**. A common task is for subjects to be shown a pair of pseudowords and **asked to press a response button** if the pseudowords rhyme."
>
> "(MRI **images) are activated by a stimulus or task** (resulting in changes of blood oxygen levels) from the combined effects of increases in the tissue blood flow, volume, and oxygenation." **[17.]**

Reading and Speech

Linking reading to speech was neurologically confirmed by the discovery that **reading words uses the same part of the brain, from "old circuits", that were used for spoken language**. **As Ehri noted, "reading is a parasite of speech".** Wolf explains how it is accomplished by the brain.

> **"Learning to read means using parts of the brain that were originally designed for other more basic processes for vision and speaking**. …..Because we do not have a gene to instruct us to read like we do for vision and speaking, reading does not come as natural to us as vision or spoken language, which is preprogrammed**. In order to perform new cultural acts, we need to use old circuitry designed for other purposes**". **[18.]**

As previously reported, speech theorist, Alvin Liberman of Haskins Laboratories, has written extensively on this aspect of reading, most of which came prior to brain image research. Ehri shows her indebtedness to the early research on the phonology of reading and demonstrates how close she came to anticipating the neurological confirmation in her Liberman quotes. 1998

> "I suggest that **establishing sight words in memory is the way that written language gains a foothold in the central mechanisms that regulate speech**. **This allows readers to use their knowledge of speech to process written language."**
>
> "…. humans are equipped for learning to produce and comprehend spoken language easily, but they are not equipped for learning to decode written language easily despite the greater powers of the eye than the ear for processing information. **Processing spoken language is not governed by "end" organs such as eyes and ears, but rather is governed by central phonological structures in the brain.** Processing speech is not a matter of processing sounds, but instead is **a matter of processing combinations of rapidly executed, co-articulated, motoric gestures that are controlled by central processes in the brain**. Such processing far exceeds the limits of the ear.
>
> **The critical phonemic segments that speakers and listeners must process do not lie in the signal itself; rather they lie in the brain and are detected and processed successfully by speakers and listeners because they both possess the same mental equipment."** p. 5 [19.]

This specialization for speech is evident in the actual physiology of the brain.

> "The left hemisphere is "somewhat larger than the right, due primarily to the left hemisphere being the repository of most linguistic related skills. As Goldberg (2005) noted, the left hemisphere tends to have more gray matter than the right hemisphere as there are more neurons densely packed together that tend to interconnect in relatively short distances. Consequently, certain speech zones in the left hemisphere tend to be larger than those in the right hemisphere." [20.]

After referring to his discovery, Feifer and Toffalo, in their 2007 publication, express the need to dig even deeper **at the neural level** to get the full explanation for how words are found and retrieved so quickly. Pg 52.

> "How does the typical pre-literate kindergarten child with a vocabulary of some 3,000 to 4000 words upon entering school develop a working vocabulary of better than 50,000 words upon graduating from high school. Furthermore, **what are the neurobiological mechanisms** that allow students to rapidly and automatically recognize a given word in a mere 200msec?"
> "The **cognitive machinery** necessary for the average child to acquire some 10 new (reading vocabulary) words per day over the next 12 years of their academic career begins with an **exploration of the neural pathways mediating the reading process.**" [21.]

Spoken Language and the Brain

According to a recently published book on the origins of speech by Tom Wolfe, in **<u>The Kingdome of Speech</u>** (2016),

> "Speech is not one of man's several unique attributes – **speech is the attribute of all attributes**! Speech is 95 percent plus of **what lifts man above animal**! …. Man owns or controls them all, every animal that exists, thanks to his **super-power: speech**…. Darwin's doctrine of natural selection couldn't deal with artifacts, which were by definition unnatural, or with the **mother of all artifacts, which was the Word**. The **inexplicable power of the Word – speech, language** – was driving him crazy…..he had no idea yet that **speech ….. was by far –very far— the greatest power possessed by any creature on earth**." [22.]

Wolfe reports that "some of the greatest minds in academia" have recently conceded that, "The most fundamental questions about the origins and evolution of our linguistic capacity remain as mysterious as ever." [23.]

Anthropologist, Ernest Becker states, "There remains a mystery (beyond the mystery of reading words) that has fascinated man since ancient times, a mystery that neither the Greeks, nor Darwin, nor modern anthropologists have been able to unravel with any certainty – I mean, of course, the "gift" of symbolic language…. We can see how it must have come about gradually, over perhaps, hundreds of thousands of years." **"language is what makes (us)** quintessentially human." **24.**

Edward Wilson, a renown biologist and naturalist, calls "Language the (holy) grail of human social evolution, achieved. Once installed, it bestowed almost magical powers on the human species. Language uses arbitrary symbols (letters) and words to convey meaning and generate a potentially infinite number of messages." **25.**

In spite of uncertainties about the origins of spoken language, as a result of new technology, much is now known about how the brain processes this greatest power, speech. Because of the "parasitic" relationship of reading to spoken language and the similarities of both instant "decoding" of speech and print, **knowing some basics about how speech works in the brain**, **reveals how it also works in reading words**.

As Ehri quoted Alvin Liberman, (see Part I),

> "In spite of the complexly encoded nature of the speech signal, **phonological structures** are in fact contained within it. **Those structures must be produced and received by the speaker and listener, whether they know it or not**, for if the structures were not, language **as it has come to be would not exist**. Moreover, it is possible to become aware of those structures, for, **if it were not**, **alphabetic reading and writing as they have come to be would not exist**.

The neurological study of speech confirms this process and reveals details on how spoken words are "decoded" quickly in listening to and taking in the lowest units of speech that make up the of various combinations of phonemes for thousands of spoken words. This is exactly how written words are also "decoded" quickly in reading, from seeing and taking in various combinations of letters that make up the printed equivalent.

In her book, <u>Overcoming Dyslexia</u>, (2005) Shaywitz describes the **speech process**.

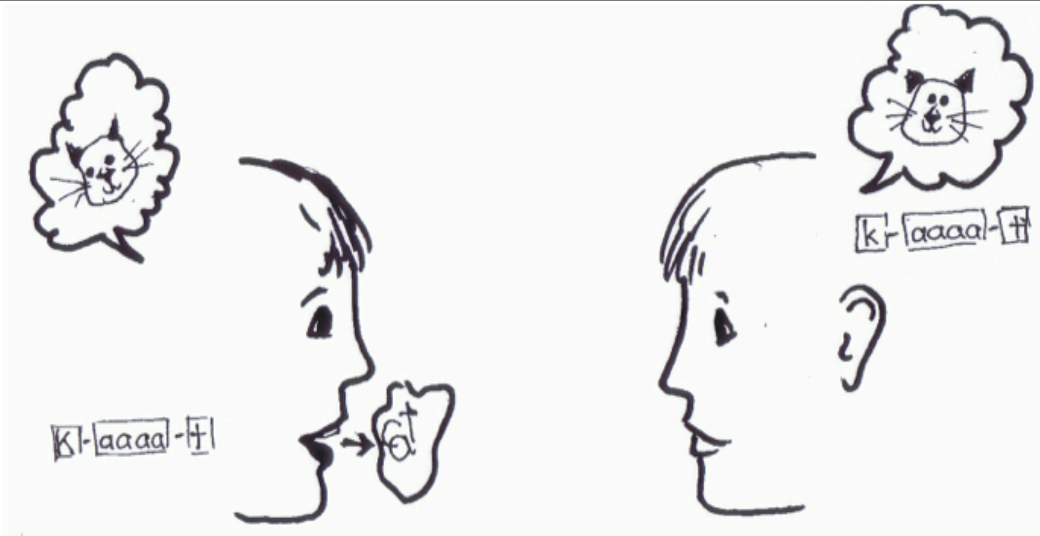
> "At the lowest level of the hierarchy (of spoken language) is the **phonologic module**, which is dedicated to processing the distinctive sound elements of language. … **(In hearing words), before they can be identified, understood, stored in memory, or retrieved from it, they must first be broken down into phonemes by the neural machinery of the brain. …. Words must be broken down into their underlying phonemes before they can be processed by the language system. Language is a code, and the only code that can be recognized by the language system and activate its machinery is the phonologic code. "**
> **"Through neural circuitry deep within our brains, a genetically determined phonological module automatically assembles the phonemes into words for the speaker and disassembles the spoken word back into its underlying phonemes for the listener. Thus spoken language, which takes place at a preconscious level, is effortless.** …. If a baby is neurologically healthy, there is almost no way she can avoid learning to speak." **26.**

The Phonological Code in Speech

(see graphic below)

> "(Sounds in words travel past the ear) into the safe haven of **cerebral neural circuits specialized for receiving language.** The phonologic module in the brain immediately activates and recovers the phonemes contained within each pulse (word or syllable), and automatically translates the sound into particles of language. **The listener receives the exact message sent by the speaker**." **27.**

> "The brain automatically processes spoken words by decoding the oral code made up of 44 small bits of sounds. **The brain does this for us.** It automatically picks up the small bits of sounds in someone's speech and makes words from them without our having to think about how it is done." **28.**



The Phonological Code

How Reading becomes attached to Spoken Language.
Because of the brain's "evolved" specialization for spoken language, letters can "piggy back" onto speech at the lowest phonological level. **This enables the brain to treat letters in written language the same as it treats phonemes in spoken words if L/S links have been learned.** For example: the brain can now learn to decode words composed from the 26 letter English alphabetic code that, in various ways, represent the 42+ phonemes in spoken English to the point where it is done as quickly as these phonemes are decoded in speech. **The brain can do this because, from learning, it can now use the same neurological mechanism, used to decode phonemes in speech, to decode letters in words. This capacity with speech makes reading alphabetic writing possible if the alphabetic principle has been learned.**

Shaywitz describes the "piggy backing" process onto speech.

> **"In order to read we must enter the language system; at a neural level this means that reading relies on the brain circuits already in place for language."**
>
> "Reading is not built into our genes; there is no reading module wired into the human brain. **In order to read, man has to take advantage of what nature has provided: a biological module for (spoken) language.** For the object of the reader's attention (print) to gain entry into the language module, **a truly extraordinary transformation must occur**. **The reader must somehow convert the print on a page into a linguistic code – the phonologic code, the only code recognized and accepted by the language system.** However, unlike the particles of spoken language, the letters of the alphabet have no inherent linguistic connotation. Unless the reader-to-be can convert the printed characters on the page into the phonetic code, these letters remain just a bunch of lines and circles totally devoid of linguistic meaning."
> **"Beginning readers** must learn how to convert an array of meaningless symbols on paper so that they are accepted by a **powerful language machinery that recognizes only the phonologic code**. … The most eloquent of written prose is rendered meaningless if it cannot be transformed into the phonologic code **recognized by that reader's language module."**
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> "As soon as the printed words are translated into the phonologic code, **printed words are now accepted by the neural circuitry already in place for processing spoken language**. **Decoded into phonemes, words are processed automatically by the language system.** The reading code is deciphered. …. It is these very same phonemes to which the letters of the alphabet must attach if the written word is to be brought into the language system. **All readers must take the same steps. The difference is simply in the effort involved and the time it takes to master the alphabetic principle."** [29]

Ehri further describes the implications of this relationship.

> "These facts about speech make it apparent why learning to decipher print is not the "natural" process that learning to speak is. The brain is specialized for processing spoken language, but it has no special central equipment for processing written language. In order for reading and writing skills to develop, what needs to happen is that **written language must penetrate and gain a foothold in the central equipment used to process speech**. **Graphemes must become attached to "deep" phonemes**, not simply to "surface" sounds within words. Such penetration and attachment, however, **are not straight-forward** steps, because **speech is seamless on the surface, with no breaks signaling phonemic unit**s. **Special experiences are needed to engage the brain in deciphering print**." p. 5 [30.]

Maryanne Wolf adds the visual component that initiates letter/sound bonding. She also stresses the impact of the added demand that reading makes on the brain itself.

> "On top if all of this, our brain has the capacity to form representations to highly learned patterns of information **in specialized regions of our brain**. **It has been found that just imagining letters triggers activations of particular neurons in our visual cortex.**

Good readers are very good alphabetic decoders, yet they do not take the time to sound out each word. **After learning letter/sound connections, thoroughly, the brain automatically, instantly, does the decoding for them and reads all words as "phonetically based sight-words".** It decodes printed words automatically for the reader so that the reader can pay more attention to higher-levels of thinking found in a text. **This is the final unraveling of the full answer to the Reading Mystery that researchers have been searching for decades. It confirms Ehri's theory and completes the solution to the mystery of how good reading can be done easily and quickly, with thousands of words, including unique English spelling complications.**

This automatic process happens **if**, through learning, letters are firmly connected, bonded, to the small bits of spoken language, phonemes. The eye must pick up letters and letter patterns, and the ear (brain) must cognitively connect them to the matched small bits of speech sounds held in memory. **If these connections are firm, the brain visually picks up the letters and forms words in the same way it does with the small bits of sounds heard in speech**. The brain can then process printed words the same automatic way as it does for spoken words in speaking and in listening. (implications for instruction, see Part III)

In time, this enables readers to read as easily and quickly as they speak and listen.

Thus, it is the innate ability to speak and listen, combined with the visual ability to identify objects and patterns of letters, performed in the same specific regions of the brain, that makes it possible to read an alphabetic writing system easily and quickly. Reading draws on the capabilities of the part of the brain that is innately designed to specialize in spoken language and for perceiving visual objects.

The act of reading makes new changes in brain development from what nature has provided. **The evidence indicates that reading, over time, has actually made changes within the brain from what it was with only speech**.

> …Groups of neurons create new connections and pathways as a result of new demands placed on it. We can learn to read only because the brain has this capacity to change. How well we read and what we read over our life-time makes unique changes within each individual. **We know that the structure, at the neuron level, of a person who learns to read Chinese is different than one who reads English.** " (sample brain images of both are available in the book) [31.]

These changes are made clear in the official, on-line publication, "Dyslexia and the Brain", by the International Dyslexia Association (IDA).

> "Brain imaging research has revealed **anatomical and functional changes in typically developing readers as they learn to read** (e.g. Turkeltaub et al., 2003), [32].

Maryanne Wolf tells how reading has **changed the way the human brain works,** from older evolutionary circuitry to where humans can read words automatically and easily. **Her description of how the brain <u>retrieves words</u> from the very epicenter of storage, after being "accessed" by the firm bonding of letters to sounds, is as close a description as one could hope for.**

> "(With reading) we rearranged the very organization of our brain, which in turn **expanded the ways we were able to think**, **which altered the intellectual evolution of our species. Reading is one of the single most remarkable inventions in history.** … Our ancestors' invention could come about only because of the human brain's extraordinary ability to make new connections among its existing structures, a process made possible by the brain's ability to be shaped by experience. **This plasticity at the heart of the brain's design forms the basis for much of who we are, and who we might become.**" p.3

She describes the inner workings of the brain during reading.

> "Underlying the brain's ability to learn reading lies its protean **capacity to make new connections** among structures and circuits originally devoted to other more basic brain processes that have enjoyed a longer existence in human evolution, such as vision and spoken language. **We now know that groups of neurons create new connections and pathways among themselves every time we acquire a new skill** – to accommodate the varying demands on it. **….we come into the world programmed with the capacity to change what is given to us by nature, so that we can go beyond it**…. **Reading can be learned only because of the brain's plastic design**, and when reading takes place that individual brain is forever changed, both physiologically and intellectually. P. 5
>
> "**At a different level of study, cognitive neuroscientists today investigate how various cognitive (or mental) processes work in the brain.** Within this research, the reading process offers an example par excellence of a **recently acquired cultural invention that requires something new from existing structures in the brain.** The study of what the human brain has to do to read, and of **its clever ways of adapting when things go wrong**, is analogous to the study of the squid in earlier neuroscience." P. 6
>
> (In reading,) "**without a single moment of conscious awareness**, **you applied highly automatic rules about the sounds of letters in the English writing system,** and used a great many linguistic processes to do so. This is the **essence of what is called the alphabetic principle**, **and it depends on your brain's uncanny ability to learn to connect and integrate at rapid-fire speeds what it sees and what it hears to what it knows….with a rapidity that still astounds researchers.**" p.8
>
> "Unlike (**reading's) component parts, such as vision and speech**, **which are genetically organized**, **reading has no direct genetic program passing it on to future generations.** … This is part of what makes reading ---and **any cultural invention** – different from other processes, and **why it does not come as naturally to our children as vision or spoken language, which are preprogrammed.**" P.11
>
> "When confronted, therefore, with the task of inventing functions like literacy and numeracy, our brain had at its disposal **three ingenious design principles**: (1) the capacity **to make new connections among older structures**; (2) the capacity to form areas of exquisitely **precise specialization** for recognizing patterns in information; and (3) **the ability to learn to recruit and connect information from these areas automatically.** In one way or another, **these three principles of brain organization are the foundation for all of reading's evolution, development, and (at times) failure**…." P.12
>
> "Critically, the combination of the several innate new connections – for 1. adaptations, for 2. specialization, and for 3. making new connections – **allowed our brain to make new pathways** between visual areas and those areas serving the cognitive and linguistic processes that are essential to written language. **(these two principles are incorporated to create) the capacity of the neuronal circuits to become virtually automatic. (which) does not happen overnight.**

> "…. For example, **as the networks of cells responsible for recognizing letters and letter patterns learn to 'fire together', they create representations of their visual information that are far more rapidly retrieved**. .. **It has been found that merely imagining letters results in activation of particular neurons in our visual cortex.** For the expert reading brain, as information enters through the retina, **all the physical properties of the letters are processed by an array of specialized neurons that feed their information automatically deeper and deeper into other visual processing areas. They are part and parcel of the virtual automaticity of the reading brain in which all its representatives and indeed all it individual processes – not just visual ones- become rapid fire and effortless.** " P.14-15 [33.]

The distinctions between the three kinds of word reading that Ehri sought to make in her experiments**:** memorization, decoding or phonologically based cipher sight-word reading, have been made clear in the neurological studies. They do this by showing that memorizing words, as non-alphabetic graphics, uses a different part of the brain. They are treated as pictures of objects, not as words the way the brain reads or listens to words. The working of the brain by those who read Chinese words looks different than one who reads an alphabetic language. (see foot note #31)

Neurological studies also revealed the **hidden "shift" from slower decoding to instant phonological sight word**, that was difficult to distinguish in Ehri's reports. (see Part Ia) Each kind of reading is performed by a different part of the brain. (see below for this description.) Brain imaging makes it possible to know more about what's going on in the brain of skillful "cipher sight-word readers" so that these distinctions can be understood and applied to teaching with better clarity. This relationship between the behavioral studies and neurological imaging studies have been described by Ehri on one side and Sally Shaywitz on the other.

With the figure below, Saywitz describes the process that makes the distinction between the way the brain treats decoding and cipher sight-word reading clear.

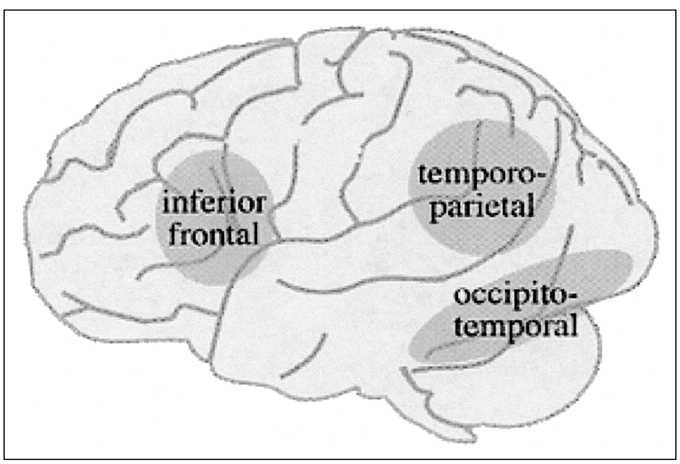

Fig. 8. A simple schematic of some of the left-hemisphere brain areas that are involved in word reading (based on Fiez, in press). (Some right-hemisphere areas are also involved in reading.) Research suggests posterior areas (occipitotemporal) may include structures specifically involved in orthographic processing of printed words (i.e., a visual word-form area). Both left inferior frontal and temporoparietal regions play a role in word reading that involves phonological processing.

How Psychological Science Informs the Teaching of Reading, Brain imaging, pps 50 & 51,
Rayner, K., Foorman, B., Perfetti, C., Pesetsky, D. & Seidenberg, M. 2001

> "As they read, good readers activate highly interconnected neural systems that encompass regions in the back and front of the left side on the brain. … Most of the reading part of the brain is in the back. (two regions, one

little higher) (This is where) all the relevant information about a word – how it looks, how it sounds, and what it means – is tightly bound together and stored."

"Beginning readers must first analyze a word; skilled readers identify a word instantaneously. The parieto-temporal (higher region) system works for the novice reader. Slow and analytic, its function seems to be in the early stages of learning to read, that is, in initially analyzing a word, pulling it apart, and linking its letters to their sounds. In contrast to the step-by-step perieto-temporal system, the occipito-temporal (lower) region is the express pathway to reading and is the one used by skilled readers. The more skilled the reader, the more she activates this region. It responds very rapidly – in less that 150 ms (less that a heartbeat)- to seeing a word."

"Here's how we think the word form system works: After a child has analyzed and correctly read a word several times, he forms an exact neural model of that specific word; the model (word form), reflecting the word's spelling, its pronunciation, and its meaning, is now permanently stored in the occipito-temporal system. Subsequently, just seeing the word in print immediately activates the word form and all the relevant information about the word."

"A third reading pathway, this one in the Broca's area (front, left) in the front of the brain, also helps in slowly analyzing a word. There are therefore three neural pathways for reading: two slower, analytic ones, the parieto-temporal and the frontal, that are used mainly by beginning readers, and an express route, the occipito-temporal, relied on by experienced, skilled readers." Shaywitz, pps 78-82 [34.]

Conclusion: All reading of an alphabetic language eventually becomes primarily phonological. The printed alphabetic words get hooked onto internal speech mechanism, whether taught or not, whether wanted, or not. In time, it's not a choice. It's "obligatory", automatic, just happens like speech is automatic. This is the final solution to the mystery of how are humans able to read as well as they can read. Some can learn to read this way mostly on their own, with practice and exposure. Others never do, at leas not well, unless taught. The safest route is to make sure all do learn as soon as possible to get children into reading as soon as possible.

WHAT CAN GO WRONG TO RESULT IN DYSLEXIA?

Having to "rearrange" the brain to accommodate for letters in learning to read, without a gene to give direction, means that bonding letter/sound connections **that make these changes is not an easy task for hardly anyone**.

"If there are no genes specific only to reading, and if our brain has to connect older structures for vision and language to learn this new skill, **every child in every generation has to do a lot of work**." [35.]

As neurologist, Steven Pinker states, " Children are wired for sound, but print is an optional accessory that must be **painstakingly bolted on.**" (cited in M. Wolf. 2007, p. 19) [36.]

However, due to the added cognitive demands from an alphabetic print, <u>reading places an added burden</u> on the specialized phonological areas of the brain, innately devoted to speech. Readers have varying degrees of difficulty, some to a severe degree, in meeting these new demands for reading. **The varying degrees of capacities within this neurological region, like any other human ability, tend to be evenly distributed among the general population, represented on a bell-shaped curve**. Those with abilities at the lower end of the curve have difficulties meeting the new demands. This condition is a reading disability called dyslexia. The condition varies along a continuum from mild to severe. It has the largest effect on learning L/S bonding. This helps to explain why phonological weakness in reading is the most common characteristic of those that have difficulty learning to read.

It is important to recognize the "normal distribution" of these conditions.

> "…science has shown it is incorrect to think of dyslexia as an "all or none" phenomena. That is, the **phonological processing abilities** required for acquisition of early reading skills **are normally distributed in the population, just like musical talent, athletic ability, or most other human abilities**. It is possible to have extremely weak phonological processing skills, or to be only mildly impaired in this area. It is also possible to have above average skills in the phonological domain. **If students have extreme phonological processing weaknesses, it is very, very difficult for them to acquire early reading skills,** while students with mild difficulties in this area often require only a moderate amount of **extra instruction** to become good readers . [37.]

Whereas the intensions of Ehri's experiments were to uncover how words are normally read, in the process, an important unexpected by-product was gained. In her studies, it was found that **not all** children could "spontaneously" make matches of letters to sounds equally well. Some did not make any connections, even with the simplest spellings. Thus, for many children, making early and partial letter/sound connections in early learning seemed almost natural. **For others, the results indicated a weakness in detecting the sounds in speech, heard in the pronunciation of words.** No letters were connected to any parts of the words for these children. **This weakness has become an accurate predictor of specific neurological conditions that lead to difficulties in learning to read, leading to a new non-visual concept of dyslexia.**

How dyslexia is explained

In the history on the topic of reading disabilities, before the onset of brain-imaging, researchers had narrowed the primary source to **difficulties with the letter/sound relationships, meaning decoding.** That much was easy. **As important as visual learning of letters and letter patterns is, the major difficulties did not lie with learning visual distinctions.**

It was found that the source of the difficulties lied with the detection and use of the small bits of speech sounds. It eventually became hypothesized, confirmed later by brain-imaging, that the cause of this difficulty resides in the "phonological module". The difficulties lie with varying levels of phonemic sensitivity to, awareness of, and articulation of the hidden phonemes for making the correct match to letters from the speech side.

The brain may adequately detect phonemes for speech (automatic), but it is less efficient **when demands are increased for the alphabetic <u>connections</u>** to phonemes in reading or writing. Any weakness in the phonological module may result in difficulties in meeting this added demand. "A phonological impairment that affects reading may have only subtle effects on producing or comprehending speech." [38.] (Seidenberg, 2017, p. 165)

> "The phonological processing problems of students with dyslexia are usually not severe enough to interfere with the acquisition of speech, but they sometimes produce delays in language development, **and they significantly interfere with the development of phonemic awareness and phonics skills for reading**." [39.]

> **"reading may be the stressor that exposes a phonological deficit that can go undetected in spoken language.**"
> "Either way, the phonological deficit hypothesis has a large scope: **all difficulties in reading may be due to phonological deficits.** The upward reach of the hypothesis was clearly expressed by Shankweiler (1989): Difficulties at each level (the word, the sentence, the text) might stem from a deficit in phonological processing. This deficit was not about phonemic awareness, which came to be seen as **just one symptom of a deeper phonological deficit**, a point made very clearly by Liberman and Shankweiler (1991)" [40.]

As indicated in many of Ehri's experiments, any **weakness that may exist in establishing the required L/S bonding reside in the phonological side** of reading, not with the print. The children having difficulties with reading words cannot hear and identify the individual sounds **sufficiently** to easily make matches with the visual letters, especially at the speed required. (see Parts 1a&b for a more detailed description of built in difficulties in phonemic awareness) Within the neurological description of the normal way the brain treats words, children with dyslexia have difficulties in the higher-left region analyzing the correct L/S matching. Children with difficulties are thus slow at developing fully connected letter-sound matching for fast, but not normally fast, sight word reading. This weakness can be observed in specific phonemic awareness tests, as well as in learning decoding skills (real words or not) and especially in fluency. This observation has important implications for instruction for those children having difficulty.

Ehri explains it this way in her **email message to the SSR listserve group**.

> "Learning to read words from memory presents problems for struggling readers. One problem involves phonological difficulties of various kinds. Studies have shown that students with a reading disability may have limited phonemic awareness (Liberman & Shankweiler), weak phonological working memory (Gathercole), and their phonological representations of words may be imprecise. Another problem is that they have not mastered the major grapheme-phoneme relations so this limits their ability to phonologically decode unfamiliar words (Rack, Snowling & Olson). As a result, they lack the requisite skills for forming complete connections between spellings and pronunciations of words to store them in memory. **The connections are partial and incomplete.** When they encounter unfamiliar words in text, **they compensate for poor decoding skill by predicting words using partial letters and context cues** (Stanovich**). As a result, they do not retain fully connected words in memory to support accurate sight word reading."**

A growing consensus has documented the importance of phonologic knowledge and skills for reading.

> "The awareness of the phonological structure of language is the basis for accurate recognition of known words necessary for basic reading." P. 88 [41.]

Weakness in this vital area has been identified, by a variety of sources, as the primary cause of reading disabilities.

> "An overwhelming amount of evidence indicates that the proximal impediment to reading in at-risk and reading-disabled children is difficulty in recognizing words. …lack of skill at recognizing words is always a reasonable predictor of difficulties in developing reading comprehension ability." p. 4 & 5

> "We know unequivocally that less-skilled readers have difficulty turning spellings into sounds. This processing deficit is revealed by the most reliable indicator of a reading disability: difficulty in rapidly and accurately reading pseudo words. … This relationship is so strong that it deserves to be identified as one, if not the defining feature of reading disability, at a fairly or proximal level of processing. ..the basic finding remains: problems with spelling-sound conversions are the defining features of reading disability**."** p. 9 [42.]

> "There is voluminous evidence that reading difficulties are associated with poor performance in tasks that demand a deep form of phonological sensitivity – in particular, tasks that require the more explicit forms of phonemic segmentation." p.12 [43.]

This weakness also has harmful consequences to higher order reading skills.

> "The persistent failure of the word recognition module to present central processes with the real-world knowledge, complex syntactic structures, decontextualized arguments, and vocabulary that are present in written language may have severe and snowballing effects on the development of higher-level processing operations." p. 331 [44.]

Until brain image research was conducted, the explanation for this weakness between phonological sensitivity and word reading was left somewhat vague. With the new technology, however, "**behavioral and imaging studies of dyslexics, and clinical studies converge on a core deficit in phonological representations or phonological processes."** [45.]

Dyslexia Defined and Further Described

The most severe weaknesses in this process is a condition commonly referred to in research literature as **"developmental dyslexia", acquired through a "glitch" in development, not through injury or ill health.** It is the "most common and carefully studied of all the learning disabilities".

> **"Dyslexia involves a weakness within the language system, specifically at the level of the phonological module.** " Shaywitz **"Functional brain imaging has, for the first time, made visible a previously hidden disability –dyslexia**, the most common Learning Disability." **[46.]**

In a 2016 published summative report by the International Dyslexia Association, the following statement was made:

> "To date, there is substantial evidence that dyslexia has a neurological basis, exhibiting differences from typically achieving readers in the structure and function of brain areas that include, but are not limited to, what is considered to be the reading network of the brain."

The report concluded that "observable behavioral deficits in reading skills have neurological underpinnings." **[47.]** These underpinnings are found in the phonological functions of the brain.

The National Institute of Child Health and Human Development, which has sponsored a large body of recent research on reading and dyslexia, along with the **Board of International Dyslexia Association,** in 2002, has adopted the following, widely accepted, **definition of dyslexia** .

> *"Dyslexia is a specific learning disability that is neurological in origin. It is characterized by difficulties with accurate and / or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge."*

> "The definition remains meaningful (in 2017) for research and for practice. It includes inclusionary criteria, which is critical. It does not specify operational criteria, which is impossible (i.e., thresholds for severity or eligibility). There should be no equating of dyslexia as a diagnosis and eligibility for special education because there must be a demonstration of educational need."

> "This definition has left its mark on research and practice and is currently contributing to policy to ensure that all children in need have access to research-based practice. Figuratively speaking, the research in reading has resulted in a *vaccine* that, given wide use, should ameliorate most difficulty in learning how to read."

> "The term *dyslexia* might fade into obsolescence like smallpox, polio, and pertussis. However, if someone didn't identify what it was, create a cure, and get that cure to the masses, we would still be hearing the term and reading about it every day. If some day, we stopped using the term *dyslexia* altogether, that might be a good thing! Right now, however, we are at a critical stage of getting the *vaccine* to the masses."

A Florida technical report elaborates on this definition:

> "The primary evidence that students with dyslexia have a problem that is inherent, and not the sole result of poor teaching or lack of experience, comes from twin studies showing that dyslexia is substantially heritable (Olson & Gayan, 2001), and **from brain imagery studies showing differences in the way the brains of dyslexic students function** (Shaywitz, 2003)." Torgensen, et al, 2008 **[48.]**

> "Converging evidence from many laboratories around the world has demonstrated what has been termed **'a neural signature for dyslexia'** that is, **inefficient functioning of left posteria systems during reading**… This evidence from functional brain imaging has for the first time, **made visible what previously was a hidden disability." [49.]**

"The role of the brain in developmental dyslexia has been studied in the context of brain anatomy, brain chemistry, and brain function—and in combination with interventions to improve reading and information about genetic influences. Together with results of behavioral studies, this information will help researchers to identify the causes of dyslexia, continue to explore early identification of dyslexia, and determine the best avenues for its treatment." [50.]

Brain imaging research **determines that much of the variation** of reduced activity is in the left brain hemisphere, an activity level less than what is normally used by readers. The brain seeks to compensate for weakness in these areas by increasing activity more in the front of the left hemisphere and the right hemisphere, not specialized for this purpose.

The differences in left and right activity among dyslexics also is evident in the anatomy of their brain.

"From a cellular level, the dyslexic brains possessed a rather unusual architecture, characterized by numerous misplaced neurons. Similarly, from a structural level, the left hemisphere of the dyslexic brains did not exhibit the classic asymmetrical pattern between the left and right plana temporale. … in some cases….. **the right plana was actually larger than the left**. … pointing toward the relative contribution of the plana temporale in the left hemisphere as being a key region in the development of phonological awareness."
Pg 55 "…focal malformations have been found and confirmed in fMRI studies, specifically in the left perisylvian region of the dyslexic brain. ** It has been speculated that ectopias and focal malformations may prevent rapid auditory processing skills, as well as repid visual-verbal processing skills, all of which lead to **deficits with reading fluency and the automatic recognition of words in print**. "**

Pg 57 "PET studies have consistently noted a decreased activation in the left temporal-parietal regions and the superior temporal gyrus (plana temporale) during phonological processing tasks such as rhyming or segmenting various sounds in words." [51.]

"..during development (of typical reading) the left hemisphere takes over the processing of words." "..this progressive development of a reading circuit is not seen the same way in dyslexia. Researchers at Yale, led by Sally and Bennett Shaywitz, first **observed an unexpected circuit at work in children with dyslexia** on a continuum of reading-related tasks from simple visual to more complex rhyming tasks. These children used more frontal regions, particularly in the developmentally important left-hemisphere angular gyrus. Most important, this group found potentially **compensatory "auxiliary" right-hemisphere regions performing functions usually handled by the more efficient left-hemisphere areas**. " p. 185 [52.]

Thus, individuals, with weaker innate abilities in the specialized area of the brain for phonological sensitivity and activity, evolved for spoken language, **have learned to use other parts of the brain for assistance when learning to read. This requires more effort and time for learning to read and for continuous reading, once learned.** Along with experiencing difficulties, these individuals are frequently confused and troubled about the cause. It takes a toll on learning, motivation and the reading process. **With the weakness untreated early, learning to read is difficult, and eventually learning to read quickly and easily is almost impossible.**

Shaywitz relates the above description of the way the brain works in reading words in contrast to how it works and adapts to phonological weakness. She also describes in further detail the neurological cause for the "glitch", that suggests that it is more than just a "weakness". Terms like "a genetically programmed error", somehow "miswired" or "faulty wired", resulting in a "phonological impairment" are used.

"The enormous complexity of the brain its initial development presents a myriad of opportunities for a misconnection or false connection. Within this context we can begin to consider the genesis of the difficulties in dyslexia. Most likely as a result of a genetically programmed error, the neural system necessary for phonologic analysis is somehow miswired, and a child is left with a phonological impairment that interferes with spoken and written language. Depending on the nature or severity of this fault in the wiring, we would expect to observe variations and varying degrees of reading difficulty." P. 68

"Fortunately, mapping the neural pathways in good readers opened the door to understanding the nature of the difficulty in dyslexic readers. …. As they read, good readers activate the back of the brain and also, to some extent, the front of the brain. In contrast, dyslexic readers show a **fault in the system**: **under-activation** of neural pathways in the back of the brain. Consequently, they have initial trouble analyzing words and transforming letters into sounds, and even as they mature, they remain slow and not fluent readers. .. Imaging studies reveal that older dyslexic children show increased activation in frontal regions so that by adolescence they are demonstrating a pattern of overactivation in Broca's (inferior frontal) region –that is, they are increasingly using these frontal regions for reading."

"This pattern of understanding in the back of the brain provides a neural signature for the phonological difficulties characterizing dyslexia. .. Brain images recorded as dyslexic readers try to sound out words show the posterior system on the left side of the brain is **not working**; instead, these slow but accurate readers are relying on alternative secondary pathways, **not a repair but a different route to reading**. In addition, dyslexics are also using **other auxiliary systems** for reading, ones located on the right side as well as in the front of the brain – a functioning system but, alas, **not an automatic one**.

"These findings explain the previously puzzling picture of bright adult dyslexic readers who improve in reading words accurately but for whom reading remains slow and draining. The disruption (of the process of analyzing word spellings and transferring them to the lower region for instant retrieval and recognition) of activity in the left posterior systems prevents rapid, automatic word recognition; the development of ancillary right side (and frontal) systems for accurate, albeit very slow, reading. These dyslexic readers have to rely on a 'manual' rather than on an automatic system for reading." **53.** Shaywitz, pps. 81-84

Shaywitz identifies a major consequence, widely observed in and experienced by dyslexic readers.

"The phonological model crystalizes exactly what we mean by dyslexia….. The phonological weakness masks what are often excellent comprehension. Dyslexics (need to) use the 'big picture' of theories, models, and ideas as a framework to help them remember specific details. It is true that when details are not unified by associated ideas or a theoretical framework (like in rote memory) dyslexics can be at a real disadvantage."

"Rote memorization and rapid word retrieval are particularly difficult for dyslexics. On the other hand, dyslexics appear to be disproportionately represented in the upper echelons of creativity and in people who….. have broken through a boundary and have made a real difference to society. I believe that this is because a dyslexic cannot simply memorize or do things by rote; she must get far underneath (go deeper into) the concept and understand it at a fundamental level. This need often leads to a deeper understanding and a perspective that is different from what is achieved by some for whom things come easier because they just can memorize and repeat – without ever having to deeply and thoroughly understand." (dyslexics don't have the choice.)

"Even when the dyslexic knows the information, the need to rapidly retrieve and orally present such information often results in the retrieval of a related phoneme, such as in substituting *humanity* for *humidity*. As a result, the dyslexic may appear much less capable than he is. On the other hand, given time and when not pressured to provide instant oral responses, the dyslexic can deliver an excellent oral presentation. Similarly, in reading, dyslexics frequently need to resort to the context to help identify specific words. This strategy slows them down further and helps explain why the provision of extra time as an accommodation I so necessary if dyslexics are to show their knowledge." **54.** P. 57-58

But there is Good News.

The good news is that growing evidence exists that indicate that, what the "glitch" is in the development of the condition of dyslexia, it can be repaired or changed. This condition can

be changed if treated early, so that the weakness in or disruption with at the phonological level of reading can be strengthened or changed to meet the increased demands for reading.

> "Brain imaging research has revealed **anatomical and functional changes in typically developing readers as they learn to read** (e.g. Turkeltaub et al., 2003), and in children and adults with dyslexia **following effective reading instruction** (Krafnick, et al., 2011; Eden et al., 2004). International Dyslexia Association, "Dyslexia and the Brain" online, 2/13/15 [55.]

A recent review found:

> "there is growing evidence from investigations that … **changes in brain activity** (and some indication for changes in brain structure) can be associated with evidence-based reading interventions. … Although more evidence points toward changes in the brain that result in brain activity more like that of typical readers, evidence of compensatory **changes** has emerged as well." (less compensatory activity?) [56.]

"More recently, children at-risk for dyslexia who received high-quality, direct instruction in phonological awareness and word-reading skills were found to have **relatively normalized patterns of brain activation following reading intervention. These findings underscore the profound benefits of timely, effective methods of reading instruction, even for those children biologically at- risk for reading difficulties."** Haskins Laboratories [57.]

Shaywitz reports on this aspect as well.

> "The brain's reliance on patterns of connectivity may have particular relevance to the teaching of reading since within these systems **patterns of neural connections are continually reinforced and strengthened** as a result of repeated practice and experiences. We can then imagine that each time a six-year-old is able to associate a particular sound with a letter, the neural pathways responsible for making this linkage **are further reinforced and even more deeply imprinted with her brain**."
>
> "One of the most exciting applications of brain imaging is just coming into use: directly evaluating the effects of specific reading interventions on the neural systems for reading. … A key question relates to whether such effective reading programs are band-aids that cover up a reading problem and perhaps encourage the development of secondary manual pathways, or **whether they can actually rewire or 'normalize' the brain."**
>
> (Recently) "we used fMRI to study boy and girls who were struggling to learn to read and who then received a yearlong experimental reading program. The progression of changes we observed was remarkable. … The final set of images obtained one year after the intervention had ended was startling. Not only were the right-side auxiliary pathways much less prominent but, more important, there was **further development** of the primary neural systems on the left side of the brain. As shown in Figure 28, these activation patterns were comparable to those obtained from children who had always been good readers. We had observed **brain repair. (strengthening**?) This may explain why children who receive effective interventions early on develop into both accurate and fluent readers. … (The) left-side posterior circuits are essential for rapid, automatic reading."
>
> "These findings provide powerful evidence that early intervention with an effective reading program leads to the development of primary, automatic reading systems and allows a child to catch up to his classmates. This is consistent with accumulating evidence that experience (such as exposure to effective reading instruction in school) drives the development of the fast-paced word form system. **After more than a century of frustration, it has now been shown that the brain can be rewired and that struggling children can become skilled readers."** [58.]

New neurological "connections and pathways" can be found in the part of the brain designed for this function. The correction requires detailed and intensive instruction to learn firm letter/sound connections so that the young reader can become a normal learner within a one or two year period. [59.]

Two kinds of Brains

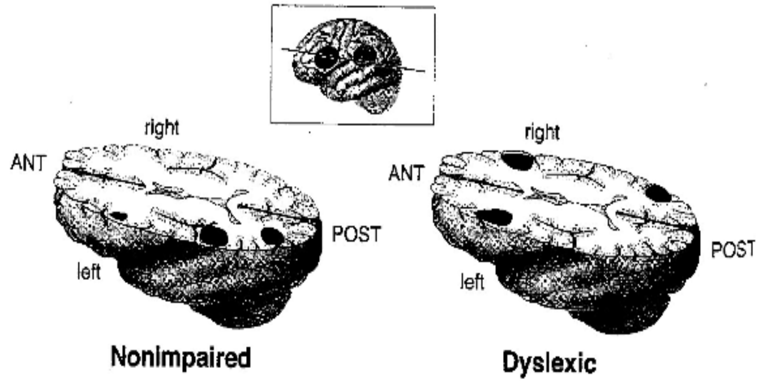

Figure 27. Dyslexic Readers Use Compensatory Systems to Read

The nonimpaired reader, on the left, activates neural systems that are mostly in the back of the left side of the brain; the dyslexic reader, on the right, activates systems on the right side and in the front of the brain on the left.

> "Some of the brain regions known to be involved in dyslexia **are also altered by learning** to read, as demonstrated by comparisons of adults who were illiterate but then learned to read (Carreiras et al., 2009). Longitudinal studies in typical readers reveal **anatomical changes with age**, some of which are related to development (Giedd et al., 1999) and **others to the firming up of language skills (Sowell et al., 2004) in correlation with improvements in phonological skills** (Lu et al., 2007)."[60.]

The best time to do to make this correction, of course, is in grades k-2.

> **"Given the knowledge of the unremitting course of dyslexia, early intervention takes on a new urgency; particularly since the data strongly indicate a much more positive response to interventions that are provided in the very first few years of school compared with those delivered in the later years of primary school**." [61.]

The Effect of Early Treatment

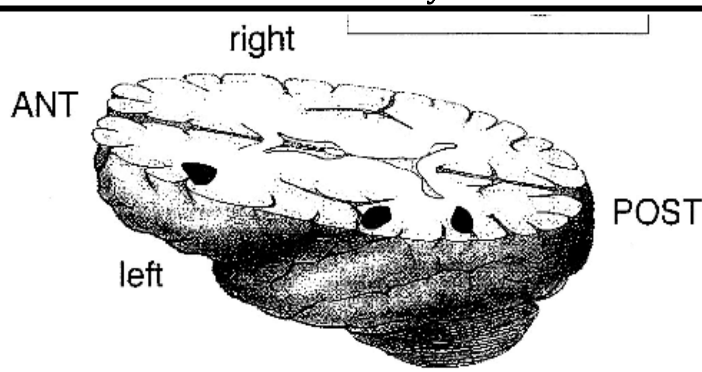

Figure 28. Effective Reading Interventions Result in Brain Repair

One year following an effective reading intervention, dyslexic children have developed left-side reading systems (shown in black) in both the front and back of the brain.

62.

(diagrams from Shaywitz's book, Overcoming Dyslexia. (2003)

In these grades, the creation of new developmental "pathways" is made easier, without a child's awareness of any difficulty. Strengthening these "pathways" for older children is harder to do, requiring more time, effort, cooperation from the child and cost. Prevention is the most desirable course of action, at the same time as continuing servicing older children needing help.[63.]

Because it is difficult and expensive to reliably identify children at a young age that may need more intensive and systematically detailed instruction, the wiser tack would be to teach all young kindergarten children this way to make sure all possible difficulties can be prevented. Intensive and detailed instruction **is helpful for all children, harmful for none, and crucial for some.** (see Part III, Critical Implications for Instruction) In so doing, those children with no problems in this area will soon become apparent in the instructional program and will be able to accelerate into more advanced reading fairly quickly. More importantly, those children needing a more intense approach will receive the kind of instruction they need in order to become normal, high-functioning readers as they also accelerate into more advanced reading.

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ADDENDUM

Attaching Written Language to Spoken Language

Charles Arthur

There is something deeply human about spoken language. Along with walking erect and tool making, spoken language is one of the hallmarks of being human. It contributes to what makes humans unique. Because of the way that written language is linked to spoken language, written language adds a deep sense of being human. Both domains of language, spoken and written, provide a means for people to participate more fully in their humanity.

Written language is linked to spoken language by the alphabet. The most basic and hidden aspect of spoken language is not words, or sentences, but the small bits of sounds, called phonemes, that give spoken words structure. The most basic aspect of written language is not the printed words, or sentences, but the letters, which represent and can be attached to the phonemes from print. This is where spoken and written language are linked. Neurological research shows that the brain automatically changes phonemes to words. It also shows that the same part of the brain can change letters to words. This is how written language and spoken language are deeply linked within the nervous system, before more complicated aspects of language come into play.

Those who have learned to read well have indelibly linked the letters to the phonemes. **The same innate human ability for spoken language also enables humans to read an alphabetic language fluently.** The only reason humans can read well is because of their innate abilities with spoken language. The ingenious invention of the alphabet in representing phonemes makes this possible. This neurological linkage binds written language to spoken language. This makes it possible to read just as well as listening and understanding speech.

The human brain changes phoneme structure heard in spoken language to meaningful words instantly, without any extra thinking. If the alphabet is linked to the phonemes, through learning, the brain will do the same thing to letters, change them to meaningful words, without any extra thinking. In both forms of language, the brain frees humans to be able to concentrate on, and think about, the meaning of words, without needing to think about the detail of letters or phonemes while reading or listening to conversation. Alphabetic writing systems make all of this possible.

For this learning to take place, the phonemes, deeply embedded, in spoken language need to come to the surface out of hiding. Humans need to be able to hear these phonemes more clearly than spoken language entails. The distinct sounds of the phonemes need to be heard within words and vocalize so that the appropriate letters can be linked to the individual phonemes. This is not a natural process. It must be taught and learned. The phonemes do not naturally exist at the surface. They tend to be bound and overlapped together in bunches, by the brain, and not individually noticed in speech. Bringing the phonemes to the surface and strongly linking them with the alphabet is an essential part of early learning to read, so that reading can become as natural as spoken language.

Problems with this learning occur because the skills with hearing and articulating phonemes in spoken language vary widely among humans. These skills, in some individuals, may be sufficient for spoken language, but are less capable of taking on the added load that written language requires. Thus, the linkage between the letters and the phonemes is difficult for some to make, a disability or weakness referred to as dyslexia. For these individuals to learn the necessary linkage, their brain must either learn to draw on other parts not specialized for language and not capable of working as automatically in decoding written and spoken words, or their brain must be strengthened in the specialized areas in early development to prevent difficulties in learning to read. This makes learning to read and the act of reading harder than usual. We now know that this condition can be treated if caught early.

The solution to this problem is to strengthen the weaker part of the brain that specializes in working with phonemes for reading so that it can take on the added load. Many recent studies have demonstrated this possibility. In order to do this, the brain must engage in activities that exercise the capacity to hear, identify and articulate phonemes in order to link phonemes to appropriate letters. In time, if treated early, this treatment makes it possible to read and write as naturally as speaking and listening. If these learning activities are successful, learning to read will be easier and everyone will be able to read as well as they can listen. As a result, their sense of being human will be enhanced.

Five Reasons for why unraveling the mystery of the Reading Puzzle is important.

1. It explains how humans can read rapidly and easily.
   Explanation:. The brain decodes words for us. The human innate ability to speak and understand speech makes this possible. The human brain does to print what it does to hearing speech.

2. It explains how this can happen.
   Explanation: With learning, the alphabetic writing code (letters) can be bonded to the oral code (phonemes) so that printed words can be decoded automatically the same way as the spoken words are decoded.

3. It then explains what is critical for all children to learn in order to be good readers.
   Explanation: The small bits of written words (letters) in words must be firmly connected, bonded, to the small bits of sounds in words. (phonemes)

4. It also explains why there is such a wide variation in the ability to read.
   Explanation: Like many other human abilities, the innate ability to decode spoken words varies among humans. This ability may be adequate for spoken words, but inadequate for the added demand for decoding written words.

5. It therefore explains why instruction must vary with children.
   Explanation: Some need more help and intensive instruction in making the necessary letter/sound connections than others. This kind of differentiated teaching can occur within small groups that progress at appropriate rates. It doesn't mean that each group will be taught with different methods and programs. Having a consistent approach with all beginners has value.