Mind Matters: The Wesleyan Journal of Psychology
Vol. 3 (2008) 5-15

Investigating the Link Between Reading Disabilities, Communication, and Developmental Disorders: Proof for the Dual-Route Model?

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Abstract
How do readers encode what they see in an efficient and meaningful way? Cognitive psychologists interested in the science of language have turned to various reading models to better understand the processes implicated in reading. Two of the more widely accepted models are the Dual-route model and the strong phonology model. The dual-rote model posits a phonological and a direct lexical route as two separate, yet interweaving routes readers use to extract meaning from written text. The strong phonology model presents only one route to reading comprehension, as the name would suggest, all emphasis with this model is placed on phonology. Strong evidence for the Dual-Route Model will be shown in the investigation of reading styles in Williams Syndrome, Dyslexia, Attention Deficit/Attention-deficit hyperactivity disorder, and Hyperlexia. To understand how the brain compensates in these individuals is to acknowledge that the strong phonology model, with only one route to access meaning, is ill-equipped to explain how we process what is read.

How Language is Processed: The Ongoing Debate

When a word is read, how is it processed? How do readers, encode what they see in an efficient and meaningful way? These are questions that have plagued, and continue to plague, cognitive psychologists interested in the science of language. To comprehend the complexities of human language understanding, many researchers have turned to models to help explain the mechanisms involved in reading. There are, unsurprisingly, many such models, though in this paper only two of the most prevalent will be of interest and consequent focus. The dual-route model, a widely accepted model for reading will be of primary focus. The strong phonology model, though a less comprehensive of a model, will serve to highlight many of the strengths of the dual-route model and many of the shortcomings inherent in reading with only one route to access meaning.

Even within these delineated models there are variations. For the sake of clarity, the broad definitions of these models within the context of this paper are as follows[1]: a dual-route model calls for a complex interweaving of two possible routes that lead a reader to understand the written word and/or speech. One is the *phonological* route where the reader uses grapheme to phoneme correspondence (GPC) rules to arrive at meaning[2]. The other route is the *direct lexical* route that calls for accessing the orthographic lexicon (or all the vocabulary a person knows), semantics, and phonology.[3] Eventually these connections work to give readers an understanding of what they have read. In this model, phonology is not crucial to word recognition. In fact, it has been posited that phonology may only be elicited in tasks that require it, specifically naming, rhyming, pseudohomophone decisions, and/or the matching of print and speech (Frost, 1998).

The strong-phonology model, on the other hand, has no orthographic lexicon in use to assemble meaning.[4] The most marked difference from the dual-route model is that in this model phonological processing is mandatory for reading comprehension; orthography is not critical (Juhasz, 2007; Frost, 2005; Rayner & Pollatsek, 1989). According to this model, when readers see a printed word they convert the letters they see into syllabic clusters and proceed to register these sounds by retrieving them from stored phonological units (*ch, k, ph,* etc.). Proponents of this model argue that phonological processing is mandatory to word processing and is henceforth automatic as well (Frost, 2005).

Various techniques for determining how we, as readers, process words have been employed in an attempt to answer the fundamental question of how we process what we read and hear. While the research done on healthy brains is essential and invaluable, it is often of great significance to examine the brains and cognitive processes, of people whose cognitive function is different or impaired in a measurable way. For this reason, I have chosen to focus on how the mechanisms in Williams syndrome, dyslexia, attention deficit disorder/attention-deficit hyperactivity disorder, and hyperlexia interfere with reading and language understanding. By uncovering what happens in cases of cognitive deficits and brain dysfunction, researchers can better understand cognition and brain function in the absence of such deficits.

Strong Phonology in Williams Syndrome

Williams syndrome is a classic example of what has been termed in cognitive development as a syndrome that exhibits selective impairments (Laing et al., 2001). People with Williams syndrome who otherwise demonstrate cognitive delay in some areas are shown to excel, or at least not demonstrate this delay, in other aspects of cognition. Disorders that exhibit selective disabilities can tell researchers a lot about what is going on in a normal brain and can provide answers to the still looming questions about reading and how it is processed.

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[1] Please See Appendix A

[2] A grapheme is the symbol a given language uses to represent meaning. Every individual letter in our alphabet is a grapheme. These graphemes can either come together to make a phoneme, or can be a phoneme on their own. A phoneme is the smallest unit of language that can convey meaning (ex: the *c* in cat and the *r* in rat are phonemes because the letter *c* and the letter *r* are what differentiate between a feline and a rodent, respectively). Phonemes come together to create morphemes, or words, that make up written language.

[3] Phonology is concerned with the speech sounds of a given language. Orthography describes and defines the set of symbols that make up a written language.

[4] Please See Appendix A for further clarification on this point

Williams syndrome (WS) is a rare neurodevelopmental disorder that usually entails physical abnormalities, mental retardation, and learning disabilities, among other symptoms; all of these symptoms vary in severity from patient to patient (Karmiloff-Smith et al*.,* 1997). In this way, the symptoms mirror many that are found in severely autistic children with one major difference: WS is also associated with excellent linguistic skills which include reading comprehension and speech (Karmiloff-Smith et al*.,* 1997; Grant et al*.,* 1997). These findings, coupled with findings that show that those with WS have debilitated spatial skills, demonstrate that while other non-linguistic cognitive skills have been delayed, linguistic capabilities remain intact. Thus individuals with WS display an understanding of morphological and grammatical rules that is often at a mental age-appropriate level (Clahsen & Almazan, 1998). It is important to note the use of mental age here, because the linguistic capabilities of subjects with WS are still a controversial topic; most research supports the idea that WS subjects do perform, linguistically, in accordance with their mental age (Laing et al., 2001; Clahsen & Almazan, 1998; Grant et al*.,* 1997; Karmiloff-Smith et al*.,* 1997).

WS subjects favor the usage of low frequency words (i.e., *newt, salamander,* and *weasel* for common animal names), produce complex sentences, and are good story-tellers (Laing et al*.,* 2001). This unusual use of low frequency words coupled with high vocabulary scores has led researchers to conclude that subjects with WS process semantic information differently (Laing et al., 2001). In order to further investigate this conclusion, researchers have turned to investigating the interplay of phonology and semantics in WS. Grant and colleagues (1997) designed an experiment that sought to measure phonology and, more importantly, how phonology and semantics (or lack thereof) affect how WS subjects learn to read. By researching the mechanisms elicited in reading in individuals with WS, researchers can come to better understand what mechanism might be at work in normal readers.

For the first part of their experiment, Grant and colleagues (1997) examined reading levels in subjects with WS via their relationships with reading and phonological skills. They administered phonological awareness and phonological processing tasks that they had previously found to correlate with individual difference in reading skills in normal readers. They employed a battery of tests that ranged from reading and spelling to rhyme detection. The results were then compared to a control group of cognitively normal developers of matched mental age. They concluded that the key difference in reading and comprehension abilities in participants with WS was the extent and effectiveness of their use of phonology. These findings seem to affirm the claim of the strong phonology model that sound alone can elicit enough meaningful information to understand what is read. Before jumping to any conclusions, it must be addressed that this study alone does not tell us much about the process of reading, but rather looks at the product of such learning. In other words, this experiment only tested subjects on what they already knew, not on any novel word-learning to see how such novelty might be processed. Their second experiment was meant to address this latter issue.

A word learning task was the focus of the second study, though it also included a measure of imageability of words for WS participants. Words such as *tree* and *car* would have high imageability, for example, while words such as *wish* and *lost* are deemed to have low imageability. Three-letter strings were used as visual cues to represent whole words. There was a phonemic condition cue, in which the middle phoneme was similar to the target word, and non-phonemic condition cue, in which it was not. For example, a target word such as *ladder* would have the phonetic cue of *ltr* and a control cue of *lkr*. The sounds present in *ltr* are similar to the sounds in ladder, while the sounds present in *lkr* are not. As mentioned, this study also included a measure of imageability, therefore, half of the words were high in imageability and half were not (rated on a scale from 1-7).

In study one, acquisition of sight vocabulary was well performed by the control groups and those with WS. In the second study, however, cue learning was overall less effective as the WS group was not aided by highly imageable words such as *ladder*. Moreover, both groups seemed to benefit from the phonological cue over the control cue (*ltr* instead of *lkr*). What Grant and colleagues proposed in light of these findings is "for the typically developing children learning . . . is mediated by creating mapping between orthographic form of a word and its phonological and semantic representations." They attributed the WS group's slower rate of learning to "failure to create this mapping" (2007, p. 737). This study as a whole provides strong evidence for the benefit of a dual-route model. The WS subjects were able to use phonology to differentiate between beneficial cues (*ltr)* and distracter cues (*lkr)*, but their failure to map this information to semantic representations of the given words hindered their overall performance. These results demonstrate that while a linear strong phonology model can be employed with some success, it is more efficient for the reader to employ a method that combines phonology, orthography, and semantics.

Karmiloff-Smith and colleagues (1997) conducted a study that reached similar conclusions. This study sought to determine if WS sufferers do have an intact grapheme-phoneme correspondence rule understanding (GPC). Based on results such as those discussed by Grant and colleagues (1997), many studies done on WS patients assume that patients suffer as a result of damage to the dual-route model pathway while the remaining language abilities are unaffected. Due to this assumption, WS is often used as a prime example of evidence for "modularity and the innate faculty for grammar" (Karmiloff-Smith et al., 1997, p. 247). The main claim in these studies is that the mental delays are localized and isolated to a specific subset of reading skills. Karmiloff-Smith and colleagues refuted this assumption and sought to point out that while language skills remain impressive in WS patients, they still lack a -*within*-domain ability to use GPC rules correctly. In other words, WS patients in this study demonstrated difficulties with grammatical gender assignments and lacked an understanding of embedded sentences. Since Karmiloff-Smith and colleagues considered these two skills to be quintessential linguistic skills, they proposed that WS patients simply do not acquire, and therefore make use of, language in the same way as controls.

Karmiloff-Smith and colleagues performed an experiment involving monolingual French-speaking WS patients and their ability to assign and understand gender in regular and non-word cues as compared to controls. It was found that WS participants were almost always 100% correct in their repeat pronunciation of a novel word. They had no trouble repeating the word back, but had significant difficulties assigning and understanding the correct gender of said word. Control participants, on the other hand, often had difficulty remembering pronunciations for the non-words, but had little trouble with gender. The proposed reason for this is the control participants, upon hearing a novel word, activated related words and their meanings, sounds, and strings. The focus for the controls was remembering the word in terms of how it might relate to similar words and their meanings, a great skill for memory retention and vocabulary expansion. The trade-off is that these connections that usually serve to help us better process and understand language confused the controls in their pronunciation. The WS participants, presumably relying heavily on a strong-phonology type model, had no trouble pronouncing the words because they did not have these "distracting connections" to muddle their pronunciations; however, they had trouble with gender assignment precisely because of this lack of connections (Karmiloff-Smith et al., 1997).

Without the ability to put the novel words in some sort of context, the WS participants were unable to understand the words on the sentence structure level, which is a major deficit. This study further suggests that a strong-phonology model alone could not suffice to explain how native speakers of languages that use gender (French, Spanish, etc.) do so with ease at a very young age. Normally developing children have no problem learning words in accordance with gender, just as English speakers seem to develop a natural sense of subject verb agreement. The fact that the WS participants who were native French speakers still had trouble with gender assignment shows that WS participants acquire language less efficiently than the controls, and that difference lies in the sole use of phonology in WS participants. Without the orthographic connections afforded to the controls, the WS participants were not able to integrate their newly learned words into their language system.

Though these studies may have tested their WS patients in different ways, the overarching results of these studies are clear. The dissociable damage that appears to exist in WS between delays in non-linguistic ability and intact linguistic capabilities speaks to the idea that if they do have some form of a dual-route model it is likely damaged. As Laing and colleagues (2001) demonstrated, the reading abilities of WS patients vary in parallel with their use of phonology. Taken at face-value, one might conclude that this supports a strong phonology model because WS patients are so adept with language. Upon closer inspection, it becomes clear that phonology is far less effective without the periphery connections postulated in the dual-route model. The above-mentioned studies articulate that WS patients may come to learn language in a different way than controls, as they are forced to circumvent the key route that control subjects use to understand and map orthography, semantics, and phonology.

Developmental Dyslexia

Developmental dyslexics have their most marked symptom in the unexplained difficulty with word recognition, in reading and sometimes writing. These difficulties can, and do, coexist with average to above-average cognitive abilities otherwise. What then is the root of the problem with dyslexic readers? The answer seems to lie with phonological processing, or the lack of it.

Studies done with functional magnetic resonance imaging (fMRI) have shown that dyslexics are most impaired with tasks that put heavy emphasis on phonological processing, such as rhyming, sounding out pseudo-words, counting of syllables, etc. (Zeffico & Eden, 2000; Simos et al., 2002). There is a general deficit in phonological representation and a behavioral deficit when phonological information in the environment is rapidly changing, as in normal speech. This is known as the "rapid processing hypothesis," and it states that dyslexics suffer because they have trouble discriminating between different sounds and breaking down phonemes, which in turn slows down their retention and understanding of speech and the written word (Temple, 2002). To revisit the section on WS (discussed above) is to realize that the problem is contrary to that proposed in WS. Dyslexics usually possess a good understanding of word meaning; the problem lies with difficulty in the access of these meanings that arises from a lack of proper phonological decoding.

Current neuroimaging data proposes that the deficits observed in dyslexia are due to disruptions in the left temporoparietal lobe, where it has been determined that phonological processing takes place in healthy brains (Zeffico & Eden, 2000; Simos et al., 2002). The importance of these studies is that they provide a functional neural basis for what is going wrong in the dyslexic brain. The problem has been localized to an area of the brain where normal phonological processing should occur; thus, researchers have come to understand that it is this disruption of normal phonological processes that causes difficulty in reading and writing. Though the true cause of these disruptions is unknown, the fact that they exist across cultures, languages, and age groups gives strong support to the idea that a dual-route model must be in place (Temple, 2002). For if phonology were the sole route for access of meaning, dyslexics, in accordance with the current research, would struggle immensely to understand the written word on their own. Since this is not the case, it is clear that developmental dyslexics rely heavily on other aspects of word processing, suggesting their brains are not bound by the strong phonology model.

Researchers who claim that dyslexia is more than a phonological impairment have refuted the above statement by claiming that dyslexia has broader implications for the difficulty it causes its sufferers. According to cerebellar theory, these difficulties are all linked to the fact that dyslexics often demonstrate various motor impairments along with their difficulties in reading. A study done by Ramus and colleagues (2003) sought to investigate the cerebellar theory of dyslexia by testing motor and phonological skills in dyslexics and controls. The results are equivocal: they found 59% of the dyslexic children to have impairments in their motor skills as compared to the control group. They also found, however, that the remaining dyslexic children demonstrated no such motor impairment. All of the dyslexic children performed well below standard on phonological tests.

The above-stated evidence is insufficent to claim cerebellar dysfunction as the cause of phonological dysfunction. The motor deficits seen in dyslexics can co-occur with reading impairment for too many reasons to clearly point to a simple answer (i.e., ADHD or other behavioral disorders). Symptoms that co-occur in dyslexia should not be taken as causal or even linked with one another. The overarching claim in many dyslexia studies is that dyslexia involves a problem with phonological processing, regardless and in spite of any other seemingly related findings (Ramus et al., 2003).

The fundamental issue with attempting to study dyslexia is that children with dyslexia will often demonstrate different dysfunctions in specific areas, such as reading, phonology, writing, and spelling,. When conducting studies, researchers focus on domains of their expertise; as such, the literature on dyslexia is fragmented, and does not add up to a coherent understanding. Even papers that have attempted to compile the studies on dyslexia leave the reader with a seemingly endless list of hypotheses and possibilities. Phonological impairment thus remains the clearest and most convincing conclusion drawn about developmental dyslexia (Fawcett & Nicolson, 2003).

Overall, the deficit seen in developmental dyslexics is opposite of what has been discussed regarding WS. Developmental dyslexics suffer from a deficit in accessing word meanings that stems from dysfunction in a localized region of the brain linked to phonology. Fundamentally, dyslexics can still decode the written word. Therefore, there are two possible explanations with regard to the strong-phonology and dual-route models. If strong-phonology is the sole system used for reading comprehension, one could postulate that dyslexics use some sort of cortical remapping to get around the dysfunction in phonological processing. While such cortical plasticity is not impossible, the more parsimonious explanation favors the dual-route model. Neuroimaging data positing damage to phonology strengthens the argument for dual-route because it confirms that if phonology were in fact the sole process to accessing meaning, dyslexics would most likely be unable to decode the written word (Fawcett & Nicolson, 2003).

Attention-Deficit/Attention-Deficit Hyperactivity Disorder & Reading Disabilities

The problem of co-occurring symptoms is prevalent in the study of behavioral disorders. One such co-occurrence is often addressed in studies that attempt to uncover the link between attention-deficit/attention-deficit hyperactivity disorder (ADD/ADHD) and disorders in reading (RD). Taken together, these disorders are two of the most common developmental disorders seen in childhood (Tomblin et al., 2000). Two questions arise: First, are they two different issues or part of the same bundle? And second, what does the answer reveal about reading?

Samuelsson and colleagues (2004) sought to address these questions as they examined the comorbidity between ADHD and RD in adult males who were diagnosed with ADHD and RD or solely RD at an early age. The men were measured on a battery of phonology tests: non-word reading, phonological choice, and a spoonerism task.[5] They were also measured on word decoding skills with tasks such as orthographic choice and word reading.

[5] Spoonerism task was meant to elicit phonology without the “distraction” of reading text. The experimenter would read out two words and the participant would have to exchange the first

The results of these studies indicated no comorbidity between ADHD and RD in terms of the reading processes involved. Those with ADHD showed no difference as compared to controls in phonological processing or word decoding. Since the most recent definitions of RD state that difficulties arise from poor phonological processing and word decoding, it is clear that ADHD and RD do not necessarily overlap, and in this study, certainly do not overlap. The difficulties with ADHD arise in reading comprehension, not with reading alone. This may suggest that comprehending what is read mandates attention in the form of "planning, constructing, inferring, and organizing" (Samuelsson, 2004, p. 165). The fact that RD manifests from phonological deficits strongly suggests that these disorders are very different in their internal breakdown. Those with ADHD can be trained to become better readers. Phonology, then, is crucial to reading, but phonology alone is not enough for comprehension of what is read, and the lack of comorbidity between ADHD and RD suggests that a lexical route (one that encompasses orthography and semantics) however it is accessed, is necessary for comprehension (Samuelsson et al., 2004).

Hyperlexia: Implications of Hyperactivation

Hyperlexia is characterized by advanced word recognition skills paired with otherwise delayed cognitive and language skills. Researchers have taken interest in hyperlexia because of its odd pairing of a "passion for the printed word" that manifests in impressively early grasp of word reading, alongside lagging reading comprehension skills as well as lags in speech production (Grigorenko et al., 2003, p. 1085). Hyperlexia primarily manifests in children with developmental delays of some sort, but the question remains, is hyperlexia really a disability? The goal is to find out what is malfunctioning in the brain of a hyperlexic, for although they are advanced in their reading, they struggle to put this information together in a logical and understandable way.

In an attempt to explain this bizarre coupling, it has been proposed that hyperlexics memorize word patterns, or shapes, as a means of quick reading. This has been disproved, however, by studies that have altered word and letter shapes and still found exceptional reading ability in hyperlexics. In addition, the theory does not hold up when one considers that hyperlexics are more than capable of reading novel words whose shapes and patterns could not have possibly been memorized (Snowling & Firth, 1986). This does not mean that the theory is not worth examining. Children with hyperlexia, when observed with fMRI, have shown a hyperactivation of the right inferior temporal sulcus, an area of the brain implicated in visual form recognition (Turkeltaub et al., 2004). As normal readers develop, the activity measured in this area decreases; with hyperlexics, however, the activation in this area remains high even as they develop as readers. This hyperactivation could account for the confusion that hyperlexics experience with comprehension. The brains of normal readers slowly wean off this activation, demonstrating that underlying mechanisms in normal reading do not need to function at full capacity. It is simply the case that an experienced reader does not need these mechanisms to work so hard, which supports the idea of automatic processes in reading (Turkeltaub et al., 2004).

It is important to note that hyperlexia is not a derivative of dyslexia. As discussed, dyslexics have their fundamental issue in phonological processing, while hyperlexics seem to have an intact phonological representation. These distinctions are important because unlike individuals with the previously discussed developmental disorders, hyperlexics seem not only to have an intact phonological route, but also to have hyperactivated phonology, though they still perform abysmally in reading comprehension tasks (Nation, 1999). It has been shown that hyperlexic reading activates both

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sound of the first word with the first sound of the second word and then repeat the results of this sound flip aloud.

the phonological systems of the left hemisphere and the visual systems of the right hemisphere. fMRI studies have shown that there is hyperactivation in the left temporoparietal lobe for hyperlexics; this is the same area where it has been shown that dyslexics experience a disruption (Turkeltaub et al., 2004). Hyperlexia and dyslexia seem to oppose each other, demonstrating their deficits in clearly dissociable ways. Despite this fact, or perhaps because of it, they serve to prove the same point; one intact route is not enough, on its own, to take on the full task of reading.

With seemingly functional brain activation, the issue of reading comprehension in hyperlexics remains unanswered. Since hyperlexia does often occur with various forms of retardation it could simply be the case that these other disorders cause the reading problems. Or perhaps hyperlexics, who often demonstrate speech disabilities, lack a "language bridge" that could serve to connect the processes to meaningful thoughts (Tomblin et al., 2000). To investigate this further is outside the scope of this paper, though the implications of these questions will be critical to our understanding of normal reading.

Tying it All Together: Confirmation of the Dual-Route Model

Frost first proposed an explanation for the dual-route model in his 1998 paper on the topic. In this paper, he claimed that there are tasks that demand phonology and tasks that do not, though all reading tasks may benefit from the use of phonology and orthography. In order to investigate these claims from a different angle, this paper attempted to uncover the different ways language is processed in the communication and developmental disorders of Williams syndrome, developmental dyslexia, ADD, ADHD, and hyperlexia. The goal of investigating these various disorders was to reveal the cognitive processes that may underlie the various deficits in order to better understand how these processes function in the healthy brain.

To summarize, Williams syndrome patients lack the ability to map orthographic and phonetic/semantic representations. They also do not seem to be affected by the imageability of words and demonstrate deficits that vary in parallel to their use of phonology. Developmental dyslexics, on the other hand, demonstrate their most marked delay in their demonstrated difficulty with word recognition that coexists with normally functioning cognitive abilities. Patients with ADD/ADHD have often been linked to the inherent possession of a reading disability. Recent studies refute this idea, demonstrating that the reading difficulties present in ADD/ADHD are not due to the same dysfunctions that are present with the other disorders discussed. Phonology remains intact with these patients and the importance of lexical route access is exemplified by these patients as well. Lastly, hyperlexics demonstrate not simply an intact phonological route, but a hyper-activated phonology. Since they still perform poorly on reading comprehension tasks, it becomes clear that phonology alone, regardless of how strong, does not suffice for accessing meaning in reading.

There is more that needs to be investigated in the field of reading and reading comprehension. That being said, the current research on reading disabilities and how they arise in the brain makes a strong case for the dual-route model of reading. The investigations of the disorders all demonstrate different forms and expressions of reading impairment. What ties these disorders together, is the fact that certain aspects of reading can remain unaffected while others are measurably impoverished. This dissociable damage could not exist if reading comprehension utilized only one route to access meaning. The strong-phonology model is far too linear to explain all the dissociations researchers find in reading and reading comprehension.

The link is clear between reading disabilities, communication, and developmental disorders. Phonology is crucial to functional reading comprehension. Those who suffer damage to phonological processes may still possess the ability to read, though it is likely that learning to read for these individuals will demand the use of different strategies. The brain has an amazing ability to cope in spite of damage or disorder. The importance of continuing to study these disorders, and reading comprehension in general, is that once researchers understand the inner workings of the dual-route model, they can better understand how to address reading when this model is damaged in some way. In doing so, researchers may find a way to curtail the negative effects of a lack of phonology, and in essence, begin to find ways to alleviate the difficulties that plague those who struggle to comprehend what they read.

Keera Bhandari is a senior psychology major. Her focus is in cognitive development and social cognition. She plans to continue her research in child social cognition for her Masters degree. *She would like to extend thanks to Professor Juhasz for her expert advice as well as to Jeff Walker, Caterina Di Perri, and Yumin He for helpful comments and insightful guidance during the editing process.* *Correspondence may be addressed to kbhandari@wesleyan.edu.*

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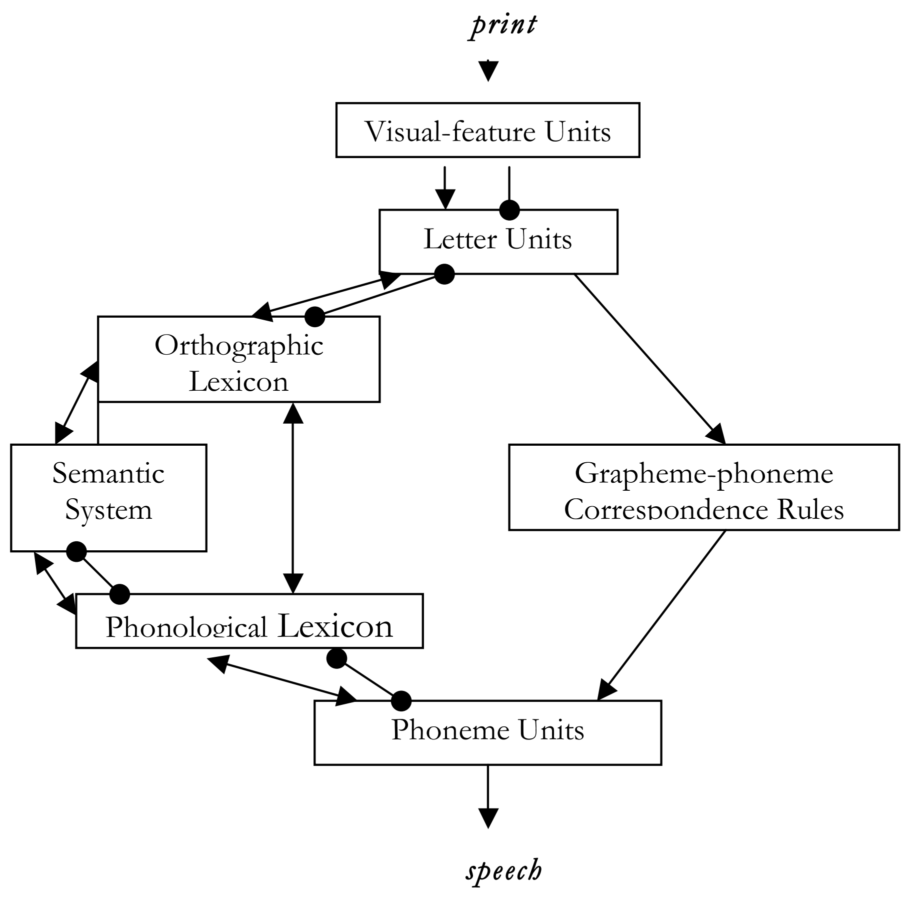
APPENDIX A

Dual Route Model (Coltheart et al., 2001):



This diagrams how the printed word is understood and translated into spoken word through the dual-route model. According to this diagram, the base visual features of a word are extracted first. This information then accesses the orthographic lexicon as well as the phonological lexicon through semantic meaning. The other route compares the visual cues of the words to memory of previously read words in order to provide a "check" for the orthographic lexicon, as well as to streamline the entire word-access process.

The strong phonology model, on the other hand, has not direct orthographic to semantic system connection. A reader works only with letter units, grapheme-phoneme correspondence rules, and their phonological lexicon (all the speech sounds a person knows).