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ABSTRACT

This literature review provides support for the idea that subtle anatomical and functional deviations in the brain correlate with specific types of reading disorders. It finds evidence that symmetry or reversed asymmetry in the plana temporale may be associated with difficulty in acquiring sound/symbol relationships. Studies are reported to show that two distinct subtypes of dyslexia exist: namely phonological, a lack of auditory awareness, and orthographical, a lack of sight awareness, with phonological processing critical to early reading development and orthographic processing important for developing automaticity of word identification and efficient reading speed. Evidence implying that the inferior parietal area is associated with such higher order processes as word meaning and comprehension is also summarized. Individual sections of the paper address the following topics: structural deviations (the plana temporale), functional implications, hemisphere shifting and the role of the corpus callosum, and reading comprehension. The paper concludes that a greater understanding of the neuroanatomical features underlying reading will lead to more effective remediation. (Contains 19 references.) (DB)

NEUROPSYCHOLOGICAL FEATURES OF DYSLEXIA

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Observed within the context of millions of years of human evolution, reading and literacy are a relatively new phenomena, encompassing only the last 5000 to 6000 years of human history. Nevertheless, the ability to synthesize visual codes into meaningful thought and communication has been at the hallmark of modern civilization. While literacy estimates have ranged from 75 to 90 percent in this country, approximately one-third of the world's population are illiterate (Rosselli, 1993). However, the influence of literacy goes beyond the scope of shaping our culture and fueling the technological advances of human civilization. To some, literacy may be at the forefront for understanding the cerebral organization and functional adaptability of the human brain.

The term developmental dyslexia refers to an inability to acquire functional reading skills despite the presence of normal intelligence and exposure to adequate educational opportunities. Developmental dyslexia represents the most common type of learning disability, affecting an estimated 5 to 10 percent of school-age population, and assumes a neurological base (Schultz, et al., 1994). Efforts to understand the neurobiological mechanisms related to dyslexia have focused on those neural systems serving language, primarily in the perisylvian association cortex in the left hemisphere (Schultz, et al., 1994). An analysis of the specific brain regions associated with dyslexia have come from electro-physiological studies, regional cerebral blood flow profiles, positron emission tomography (PET) studies, and postmortem examinations. Each procedure is strife with a certain amount of methodological flaw inherent at the outset. For instance, Hynd & Semrud-Clikeman (1989) have sharply criticized some of these studies based upon failure to account for gender and handedness effects, lack of IQ reported in the control group, lack of specificity on the CT scanner used, and poor measures of reading. Nevertheless, it seems apparent that discerning the qualities of skilled vs. unskilled readers requires an understanding of the specific cognitive elements involved with reading, and their corresponding brain/behavior relationships.

Structural Deviations: Plana Temporale

Reading disorders have been classified under two distinct rubrics: namely, dyslexia with agraphia, and dyslexia without agraphia. The difference lies in whether or not a specific writing disorder also coexists. At the core of dyslexia with agraphia, is the inability to develop a phonological awareness when reading. These students can read by using their sight vocabulary to generate "visual images", though have extreme difficulty reading nonwords (McCarthy & Warrington, 1990). In other words, poor readers have difficulty understanding that words are composed of units in the form of phonemes, syllables, and morphemes. The most compelling evidence that actual structural formations of the dyslexic brain inhibits phonological processing stems from Geschwind & Galaburda (1985). In an analysis of 100 normal adult brains, 65 percent demonstrated asymmetry in the planum temporale, with the left being larger than the right. By contrast, 11 percent had a reversal of symmetry with the right being larger than the left plana. Operating under the assumption that asymmetry is a natural evolutionary consequence of hemispheric specializations, these researchers proposed that deviations in normal patterns of brain asymmetry was at the core of developmental dyslexia. Because the left temporal cortex is associated with language, specifically Wernicke's area and the angular gyrus, the greater number of cells in the right plana may reflect neuronal loss in the left, with reading being the primary functional skill altered (Flowers, 1993).

Interestingly, asymmetry of the planum temporale is visible already at 31 weeks of fetal age (Galaburda, Rosen, & Sherman, 1990). Hynd et al., (1995) also concurred that deviations in the development in the cortex generally occur between the fifth and seventh month in fetal development, with neuronal abnormalities noted in the left temporal and bilateral frontal lobes. According to Hynd, there is a big spurt in brain weight between the 24th and 26th prenatal week. This is characterized by the development of the various gyri and sulci of the brain, and once this general pattern is laid out, it remains fairly constant. Thus, deviations in the plana temporale are visible at this time. Though true developmental dyslexia may be inhibited by morphological differences from birth, it remains unclear whether reversed symmetry in specific regions are actually the direct cause for developmental dyslexia. According to Hynd, Marshall & Semrud-Clikeman (1991), it is important to note that approximately 30 percent of <u>normal</u> brains show symmetry or reversed asymmetry (right plana larger than left) in the temporal plana, and have absolutely no difficulty with reading. Therefore, the more important variables in dyslexia may not be the actual deviations in symmetry, but rather the pattern and extent of these deviations.

Further studies by Hynd & Semrud-Clikeman (1989) have also implicated deviations from normal asymmetry in the insular cortex, and in more subcortical regions such as the thalamus to be associated with dyslexia. Specifically, the lateral posterior nucleus of the thalamus plays a vital role in intrasensory integration by projecting information to the parietal-occipital-temporal association cortices. The interface of these regions is generally referred to as the inferior parietal lobe, characterized by both the angular gyrus and supramarginal gyrus. It should be noted that the thalamus has been implicated in a variety of other developmental language disorders (Hynd & Semrud-Clikeman, 1989).

<u>Functional Implications:</u>

While structural differences in the brain are of interest in determining the possible underpinnings of dyslexia, they represent only _indirect_ information about the actual performance of the brain. Evidence looking at _functional_ differences in the brain between children with dyslexia and nondyslexic children come from _three_ lines of research. First, electrophysiological studies (EP) of dyslexia have shown longer latencies and reduced amplitude of the EP waveform in children with reading disabilities (Flowers, 1993). These distortions in waveform were associated with left temporal processing. Interestingly, this waveform remained consistent independent of reading improvement and through adulthood, suggesting an enduring characteristic underlying reading disabilities.

Second, regional cerebral blood flow (rCBF) profiles have shown that the left temporoparietal cortex was not activated during a rhyme detection task (Rumsey et al., 1992). Studies of cerebral blood flow have suggested a left temporal component associated with phonological encoding, and a left parietal component associated with reading comprehension. The distinction between reading decoding and reading comprehension will be elaborated on later. However, it is interesting to note that _hyperlexia_, a condition characterized by the uncanny ability to recognize words despite severe cognitive limitations, lends credence that certain neural pathways modulate reading decoding, while others regulate reading comprehension. Further evidence of separate neural structures for distinct reading functions were noted by Hynd & Clikeman (1989). Their research found that passage comprehension skills do not appear to be affected by reversed asymmetry in the temporal plana, as compared to word attack skills.

Lastly, positron emission tomography (PET) studies have found left caudate metabolism deficiencies during a phonemic discrimination task (Flowers, 1993). This bodes interesting in that it implicates more subcortical areas of the brain, and the caudate nucleus has been linked to ADHD and more habit forms of learning (Hynd, et al. 1993). As most special educators are aware, there is a strong relationship between learning disabilities and ADHD. In sum, these functional lines of research all lend support to the notion of an underlying temporal lobe dysfunction correlating with deficits in phonetic awareness and reading.

Hemisphere Shifting: Role of Corpus Callosum

While phonological processing is critical to early reading development, orthographic processing involves the rapid recognition of sight words important for automaticity of word identification and efficient reading speed. Obviously, skilled readers rely heavily on the ability to recognize most words rather than having to sound them out. Approximately 10 percent of all dyslexics are impaired in their ability to recognize words as visual gestalts, and 25 percent have a mixture of phonological and visual deficits in reading (Newby, Recht, & Caldwell, 1993). Although orthographic tasks are less widely studied in the literature, measures of reading speed have been used to detect the quality of orthographic processing.

Though studies have shown that two distinct subtypes of dyslexia seem to exist; namely phonological, a lack of auditory awareness, and orthographical, a lack of sight awareness (Newby, et al., 1993), most agree that skilled readers rely on an interactive system which tap both phonological and orthographic memory stores simultaneously. It would appear that the orthographic processing system serves two primary functions. The first allows for the actual synthesis of visual shapes and features of letters and words, and their subsequent memory store. The second is the automatic and rapid perception of whole words by shape, presumably once learned by phonologically sounding them out, so that fluent reading can take place.

According to Bakker (1992), reading and spelling are most strongly associated with right-hemisphere activity during the first two years of initial reading. However, there is a rapid shift toward left-hemisphere activity after that initial phase. Therefore, orthographic codes allow beginning readers to detect key features in words; however, by the end of 1st grade there is a hemispheric shift of reading mediated primarily by the left hemisphere. Hence, the right hemisphere control was thought to be related to perceptual-directional processing during initial reading, with left hemisphere control dictating syntactic and semantic features in later reading. Similarly, Goldberg (1981) has noted that in early stages of task acquisition, the right hemisphere should show superiority in performance, but as the skills necessary for the execution of a task are acquired and routinized, the left hemisphere should eventually gain superiority. Therefore, children who demonstrate a relatively slow and fragmented style of reading may be focusing too much on the perceptual features of the text, and although very accurate, were extremely slow readers because the process was never automatized, or shifted to the left hemisphere. This contrasted children who read very quickly, but were extremely inaccurate, and were presumed to have made the hemispheric switch to left hemisphere control too early in the reading process. This type of dyslexia, called <u>surface dyslexia</u>, is characterized by reading totally by sound, with frequent errors made. For instance, the word "lace" may be read as "lake" due to an inability to detect deviations in normal print to sound correspondence (McCarthy & Warrington, 1990).

This concept of hemispheric shifting, based upon the specific strategy used by readers to decode words, appears to be at the forefront of most research involving cerebral processing and dyslexia. Hynd et al.,(1995) examined the morphology of the corpus callosum in dyslexia, since communication and shifting between the hemispheres primarily takes place within this bundle of nerve fibers. Using MRI procedures, comparisons between the morphological structure of dyslexic 9 year-olds and a matched control group were examined. The results indicated that the genu of the corpus callosum was significantly smaller in developmental dyslexic individuals than in normal children. In addition, moderate correlations were noted in the size of the genu and splenium, and reading achievement. Hynd (1995) further noted that myelination of the corpus callosum occurs during adolescents, and the myelination process proceeds from the splenium to the genu to the rostrum. Consequently, developmental dyslexia may be associated with subtle deviations in the morphology of the corpus callosum preventing efficient interhemispheric communication, or perhaps with actual delays in the myelination process. Therefore, surface dyslexia may be an over-reliance of the left hemisphere, thus suppressing the right hemisphere to detect perceptual features of the text. Conversely, phonological dyslexia may be an over-reliance of the right hemisphere, thus suppressing the phonetic strategies of the left hemisphere.

Reading Comprehension:

While much of the focus has been on structural and functional mechanisms which allow human beings the unique quality of symbolic communication, little has been said about the higher level qualities of reading; namely, semantic processing. Deep dyslexia is a rare form of reading disorder characterized by impairments reading words with abstract meanings, but reading more concrete, easily imagined words are in tact. According to McCarthy & Warrington (1990), deep dyslexia can be characterized by semantic errors such as reading "watch" for "clock", "play" for "act", or "food" for "dinner". Often there is difficulty reading nonsense words, or words that are not readily visualized. Thus, when a written word is concrete enough to be readily visualized, it activates an image in the intact right hemisphere to assist in reading. Some have linked this syndrome tentatively to damage in the left perisylvian regions (Filley, 1995).

It is not within the scope of this paper to analyze the myriad of difficulties associated with reading comprehension. As Flowers (1993) noted:

> The brain is a highly interactive organ with many regions working together to accomplish its functions. It is not hard to imagine a task as complex as reading to involve more than one sensory systems, including an optimal level of arousal, organization and execution of a motor response, attentional control, working memory, and long-term memory, all working <u>simultaneously</u> (p. 577).

However, most agree that selective impairment in reading words belonging to certain categories, such as deep dyslexia, is the result of lesions affecting occipital-parietal regions of the left hemisphere; namely, the angular gyrus (McCarthy & Warrington, 1990). This ties in with Goldberg's (1989) theory that the neuroanatomical portions of the inferior parietal lobe, namely the supramarginal and angular gyrus, are higher level association areas chiefly responsible for categorizing information. Damage to these regions probably account for various agnosias, as well as difficulty with higher level reading skills, such as comprehension. Thus, the angular gyrus represents the interface of occipital, temporal, and the parietal lobes, which assist in more higher level cognitive tasks such as reading comprehension.

Hynd & Semrud-Clikeman (1989) have also alluded to more structural variations within the brain to account for variations in reading comprehension. Using MRI scanning techniques on three groups of children; developmental dyslexics, ADHD children, and a control group, these researchers noted that specific reading tasks were associated with specific variations in the brain. Symmetrical frontal widths were associated with poor reading comprehension among the developmental dyslexic group. Interestingly, the ADHD group also showed mild difficulty in reading comprehension with frontal widths being slightly more symmetrical than the control group. This study supports the notion for reading difficulties being related to normal patterns of asymmetry during brain development. It also suggests that some of the same underlying neural mechanisms which mediate reading might also overlap with ADHD and behavior regulation. Approximately one out of four children with a learning disability also have ADHD.

Other noteworthy types of syndromes which impact reading comprehension are neglect dyslexia and attentional dyslexia. In neglect dyslexia, a person misreads the initial (left neglect) or ending (right neglect) portions of words (McCarthy & Warrington, 1990). For instance, "this" might be read as "his", or "train" might be read as "rain". Typically, neglect dyslexia involves the left side of words more frequently than the right side since there are more alternative word beginnings than endings. Lesions to the contralateral side of the neglect are responsible, specifically in the occipital-parietal regions (McCarthy & Warrington, 1990).

In the case of attentional dyslexia, children were able to read individual words almost perfectly, but had extreme difficulty when asked to read multiple words in the same visual field. This is an extremely rare form of dyslexia, with the critical structures probably subcortical in nature (McCarthy & Warrington, 1990). Both neglect dyslexia and attentional dyslexia are examples of reading disorders at the visual level of analysis which can certainly disrupt comprehension skills.

Conclusion:

In summary, dyslexia is a complex, multi-faceted syndrome seemingly at the core of most developmental learning problems in children. It is also a syndrome which certainly sheds some light on the cerebral organization and functional adaptability of the human brain. The scope of this paper was to give credence to the notion that subtle anatomical and functional deviations in the brain correlate with specific types of reading disorders. For instance, there is evidence to suggest that symmetry or reversed asymmetry in the plana temporale may be associated with difficulty acquiring sound/symbol relationships, otherwise known as a phonological core. The development of a phonological core has been at the hallmark of dyslexia and remedial reading programs.

Studies have shown that two distinct subtypes of dyslexia seem to exist; namely phonological, a lack of auditory awareness, and orthographical, a lack of sight awareness. While phonological processing is critical to early reading development, orthographic processing involves the rapid recognition of sight words important for automaticity of word identification and efficient reading speed. Most agree that skilled readers rely on an interactive system which tap both phonological and orthographic memory stores simultaneously. Research has suggested that the inability to transfer information between hemispheres may be at the core of phonological (relying on the right), and orthographic (relying on the left) dyslexia. Hynd et al., (1995) noted that the genu of the corpus callosum was significantly smaller in developmental dyslexic individuals than in normal children.

Finally, there was also evidence implying that the inferior parietal area was associated with more higher order processes, such as word meaning and comprehension. Specifically, the angular gyrus, which represents the interface of occipital, temporal, and the parietal regions, assists in more higher level cognitive tasks such as reading comprehension. Other noteworthy types of syndromes which impact reading comprehension were neglect dyslexia and attentional dyslexia.

Though there are countless genetic and environmental factors which may account for reading disorders in children, it remains discouraging that so many remedial and special education programs remain ineffective. Juel (1988) found that the probability of being a poor reader at the end of first grade, and remaining a poor reader at the end of 4th grade was .88. Of course, there are some who believe that dyslexia is not distinguishable from being at the lower end of the normal distribution in reading, or that the confusing orthography of the English language accounts for much of the variation between skilled vs. unskilled readers. Nevertheless, current research has been focusing on early developmental signs such as rapid naming tasks, speed of retrieval of over-learned verbal labels (colors, letters, numbers, etc.), and accuracy of nonword reading as early predictors of reading disabilities (Badian, et al., 1990, & Felton, et al., 1990). Interestingly, intelligence has not been the focus of early predictors of learning disabilities. Hopefully, the ability to detect early signals of reading disorders, coupled with a greater understanding of the neuroanatomical features underlying reading, will provide the foundation for educational remediation of dyslexia.

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