Eavesdropping on the Brain: Gundersen Medical Foundation Dyslexia Research Studies

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It is widely held that developmental dyslexia is due to subtle disturbances in central nervous system function. However, so little evidence of a biological etiology has been documented that clinical diagnosis continues to be based on discrepancy and exclusion. Indeed, a recent article in* The New England Journal of Medicine *suggested that reading disability merely represents the lower end of the normal distribution of reading ability. This paper presents evidence for neurophysiological, neuropsychological, and academic differences between dyslexic and normal readers from three interrelated dyslexia research projects at Gundersen Medical Foundation. Converging data from the Quantitative Electroencephalogram Study, the Gundersen Remediation Program, and the Gundersen Reading Study support the existence of separate subgroups of dyslexic readers and suggest procedures for early diagnosis and effective treatment of dyslexia.

It has been almost a hundred years since an ophthalmologist first described a young patient with "congenital word blindness,"[1] yet little consensus exists regarding etiology, diagnostic criteria, appropriate treatment(s), or prognosis for the estimated 8,000,000 children with this hidden handicap.[2] Excess focus on isolated aspects of reading disability and the absence of positive neurological findings have necessitated a diagnosis by exclusion. Dyslexic children frequently experience three or more years of school failure before other causes of reading failure, e.g., environmental deprivation or poor motivation, have been ruled out, and the required school identification criterion of a severe discrepancy between intelligence and achievement has been met.

Confusion about the nature of dyslexia is illustrated by a recent article by Shaywitz et al.[3] in *The New England Journal of Medicine* which asserted that dyslexia is not a distinct disorder, but merely the lower end of the reading continuum. This study found that children who met school criteria for dyslexia in first grade were likely to not meet criteria in third grade even without intervention. The authors concluded that dyslexia represents a condition with varying degrees of severity, similar to obesity, rather than a discrete disorder. An alternate interpretation is that the identification procedure used in this study, a discrepancy between intelligence (as measured by individual IQ tests) and achievement (measured by nationally standardized tests), is invalid based on substantial evidence that deficient processes underlying reading disability also depress the IQ measure on which the determination of discrepancy is based.[4-7]

Shaywitz et al.[3] also failed to address the mounting evidence of neurological differences between dyslexics and normal readers.[8-14] However, the authors provided a significant service to the research community concerned with specific reading disability. Their finding of inconsistent identification using present procedures underscores the need for rigorous investigation of classification and identification procedures. The imprecision of current discrepancy procedures also highlights the need to study the functional neurolinguistic system involved in normal and disordered reading using simultaneous measurement of brain activity and behavior.

In an effort to provide a scientific approach to diagnosis and treatment of this complex disorder affecting 10 percent or more of our school-aged children, the Gundersen Dyslexia Research Center was established in 1988. Our research grew out of clinical frustration with diagnosis by exclusion and the lack of validated guidelines for prescribing treatments. In order to adequately capture the complexity of developmental dyslexia, we established three interrelated research projects: 1) The Gundersen Reading Study, a longitudinal study of reading development involving 5317 children in Minnesota and Wisconsin, 2) The Gundersen Remediation Program, an intervention project investigating effective treatment techniques for children with different types of dyslexia; and 3) The Quantitative Electroencephalogram (QEEG) and Event Related Potentials (ERP) Project, a basic neuroscience investigation of the developmental origins, dynamics and characteristics of dyslexia. Figure 1 depicts the relationship and scope of these projects. This paper summarizes the highlights of our research projects concerned with identification and treatment of dyslexic children.

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Gundersen Reading Study

–Epidemiology of dyslexia
–Course of disorder
–Early identification
–Early intervention

Date initiated: 1988 Number of subjects: 5,317
Investigators: Jane M. Flynn, Ph.D., Hossein Rahbar, Ph.D., Dennis Theede, M.A., Brenda Rooney, Ph.D.

Gundersen Remediation Program

–Treatment of dyslexia
–Differentiation of subtypes
–Aptitude — treatment interactions

Date initiated: 1986 Number of subjects: 297
Investigators: Jane M. Flynn, Ph.D., Brenda Rooney, Ph.D., Dennis Theede, M.A.

QEEG/ERP Study

–Biological basis of dyslexia
–Monitoring treatment effects
–Validation of dyslexic subtypes
–Development of clinical protocol and norms

Date initiated: 1983 Number of subjects: 362
Investigators: William Deering, M.D., Jane M. Flynn, Ph.D., Michael Goldstein, Ph.D., Joel Myklebust, Ph.D., Hossein Rahbar, Ph.D., Brenda Rooney, Ph.D., Sue Underberg

Figure 1. Overall scope of the Gundersen Medical Foundation Dyslexia Research Studies. These programs include the disciplines of psychology, neuropsychology, neurology, and neurophysiology.

QEEG/ERP Project

The electrical activity of the brain can be recorded as an ongoing electroencephalogram (EEG) during mental activity (e.g., during reading) or as ERP evoked by specific, time-locked stimuli (e.g., in response to light flashes, tones, or words presented visually or auditorially). With the advent of digital methods for quantifying these indices of cognitive activity, it has been possible to investigate a biological marker for dyslexia. While the clinical EEG has not been useful in diagnosis of dyslexia and other neurobehavioral disorders of childhood,[15,16] quantification of brain electrical energy has enabled statistical comparisons of groups classified on behavioral criteria, e.g., neuropsychological or academic variables.

QEEG evaluations of children with diagnosis restricted to dyslexia began with the report by Sklar et al.[17] that children with dyslexia, while reading, exhibited increased amplitudes of beta frequencies, known to be related to cognition. Early studies yielded sufficiently positive results to lead Duffy et al.[8] to speculate that someday quantitative neurophysiology might offer for diagnosis of dyslexia what the clinical EEG has provided in the diagnosis of epilepsy. However, while this line of research has generally separated those with dyslexia from normal readers, different results have been reported across studies.[8,9,11,15,16]

Inconsistent results may be attributable to conceptual and methodological differences across studies, including failure to subgroup dyslexic children according to patterns of neurocognitive deficits, or failure to account for age differences that might confound EEG findings. Methodologically, real differences might fail to be detected due to inadequate recording conditions (e.g., passive recording of eyes closed, resting, rather than during reading-related tasks) or to neurocognitive tasks that are not challenging enough to require effortful processing (e.g., reading at an easy reading level rather than at frustration level where accuracy is less than 90 percent). Our research has aimed at systematic investigation of issues of basic and applied neuroscience related to developmental dyslexia (particularly differentiation of dyslexic subtypes), the influence of age on EEG patterns, and level and type of neurocognitive tasks needed to elicit dyslexic-normal differences.

Subtypes of Dyslexia

Based on our hypothesis that children with different kinds of reading disability could be differentiated by distinct patterns of EEG during reading-related tasks, we compared the QEEG patterns of normal readers and dyslexic children, subgrouped according to the Boder system of reading and spelling patterns. Boder, a pediatric neurologist serving as school physician in Los Angeles, identified three distinct types of dyslexia – *dysphonetic, dyseidetic, mixed* – based on reading and spelling patterns unique to each subgroup. Further, these typical patterns appeared to fit neuro-psychological theories of how the brain processes information.[18-20]

Boder's dysphonetic dyslexics are characterized by fast and inaccurate reading with frequent substitutions ("goat" for "gate"). Their most striking misreadings are semantic substitutions ("funny" for "laugh"), and spelling is characterized by letter and syllable omissions ("rember" for "remember"). Boder theorized that dysphonetic dyslexics, unable to access the auditory analytic function needed to decode words, are deficient in left hemisphere function. Their relative strength in reading words as instantaneous visual gestalts seemed an indication of normal right hemisphere function.

In contrast to dysphonetic dyslexics, dyseidetic children have excellent auditory analytic skills. Once exposed to phonics, they accurately "sound out" unfamiliar words. However, it is soon apparent that they are unable to perceive words as wholes, and continue to rely on letter-by-letter decoding even for words encountered many times in the same passage. Their spelling is characterized by good phonetic renditions of misspelled words. To Dr. Boder, dyseidetic dyslexics seemed to demonstrate visual gestalt and memory deficits implicating dysfunction of the right hemisphere.

Finally, Boder postulated a third, mixed subtype deficient in both right and left hemisphere functions. Their basic reading and spelling patterns are similar to dysphonetic children, with numerous examples of phonetic difficulties in sounding out and spelling words. However, their severe retardation in reading, often resulting in less than third grade reading level despite years of remediation, led Dr. Boder to postulate both auditory-linguistic and visual memory/visual gestalt deficits in this group.

Our studies provided neurophysiological evidence that dysphonetic and dyseidetic subtypes differ from normal readers during reading tasks.[11-14] In the first study, twelve dysphonetic, four dyseidetic, and five mixed dyslexics between the ages of seven years, three months, and ten years, eleven months, were compared with six age-matched normal readers under passive recording conditions (eyes closed) and while reading at frustration reading level (chosen to require effortful processing by each child). We analyzed left and right temporal-parietal recordings of the average theta (4 to 7 hertz) and alpha (8 to 12 hertz) frequency bands by group to determine whether significant differences signaling differential brain function could be detected. Theta frequencies are associated with effortful processing, while the alpha frequencies are thought to measure efficiency of task

completion. The results demonstrate the importance of sorting heterogeneous dyslexic samples into subgroups that share common processing characteristics. As shown in Figure 2, all dyslexics are combined in one group for comparison with normal readers. In Figure 3, dysphonetics and dyseidetics are grouped separately. Although both comparisons resulted in statistical separation of dyslexics and normal readers, the results and interpretations of results would be quite different. From Figure 2 one would deduce that all dyslexics demonstrate less attenuation of theta compared with normal readers. In fact, Figure 3 demonstrates that dyseidetics increase in theta while both dysphonetics and normal readers show similar decreases in this particular EEG frequency band. Left hemisphere theta amplitude differentiated dyseidetics during reading (P=0.002), spelling recognition (P=0.01), and during a visual-spatial drawing task (P=0.03). In addition, left hemisphere alpha during reading distinguished dyseidetics from other groups (P=0.03).[11] These findings suggest that different proportions of dyslexic subtypes could be expected to result in different findings and interpretations of brain-behavior relationships across studies, and support the need to subgroup dyslexic children *a priori* to maximize the likelihood of finding reliable and meaningful differences in brain function.[13,14]

A second study, involving a larger sample (16 dysphonetics, nine dyseidetics, eight mixed, and 31 normal readers) and a smaller age range (eight years to nine years, eleven months), replicated the left hemisphere theta differences during reading for dyseidetic children (P=0.04). Right hemisphere theta and alpha differences were found for dysphonetic children.[11,12] Neither study provided support for mixed dyslexia as a subtype separate from the dysphonetic group; therefore, in subsequent research we have included Boder's mixed subtype with the dysphonetic group based on their identical pattern of neuropsychological deficits and lack of neurophysiological differences.

The promise of QEEG as a diagnostic test for early detection of dyslexia is evident from our analyses of average beta (13-30 hertz, associated with cognitive processing) amplitudes, which indicate that differences will be correctly identified 90-95 percent of the time with subgroups as small as four children.[14] This speaks to the large differences between dyslexic subgroups and normal readers, supporting Duffy's contention that this procedure may someday be clinically useful in diagnosis of dyslexia.[8]

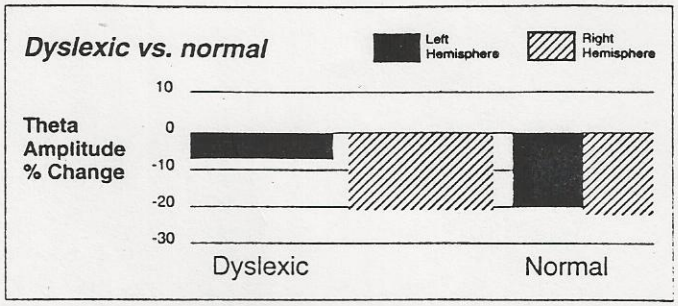

Figure 2. The percent change in left and right hemisphere theta amplitude during the transition from eyes closed to reading for undifferentiated dyslexics compared with normal readers. On the average, dyslexic children's theta amplitude over the left hemisphere decreased significantly less compared with normal children (P=0.03), whereas there was no significant change over the right hemisphere. Since theta has been found to increase initially with task engagement and then rapidly decreases with habituation, it can be inferred that dyslexics expend more energy to accomplish the same level of accuracy in reading compared with normal controls.

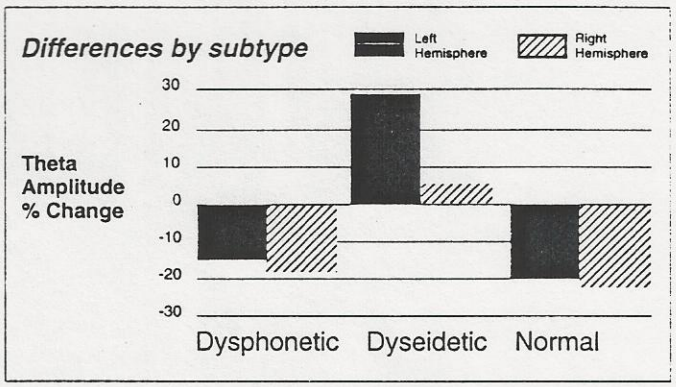

Figure 3. Theta patterns (similar to Figure 2) for subtyped dyslexics compared with the normal group. This analysis revealed a significant increase in theta amplitude over the left hemisphere for the dyseidetic group, while dysphonetics and normal readers decreased theta amplitude during reading compared with their resting baseline levels (P=0.002). The differences in the right hemisphere were not significant.

The influence of age on EEG maturation

Many of the early electrophysiological studies, including our own, studied groups with wide ranges in chronological age.[8,17,11] In our first sample, chronological ages spanned four years. Although the median age of the groups did not differ significantly, we wondered whether the chosen age range might include children with qualitatively different EEG patterns or frequency amplitudes. To test the possibility of maturational influences on EEG, we recorded a second sample within a restricted age range of eight years to nine years, eleven months. Theta differences similar to our first study were found, suggesting that EEG differences were not likely to be due to maturation.[11,12]

Passive vs. Neurocognitive Recording Conditions

Although some researchers have found dyslexic-normal differences during passive recording conditions,[8,21] others have not.[11,14] Our studies revealed few differences between dyslexic subgroups and normal readers during passive recording conditions (eyes closed), suggesting that dyslexia does not represent a gross cerebral dysfunction when the brain is not actively engaged in cognitive processing. However, recordings during reading and auditory analysis tasks have consistently resulted in a large number of differences, supporting our theory of different cerebral organization patterns in subtypes of dyslexic children.[11,14]

Level of Neurocognitive Challenge

There is also some suggestion that tasks chosen to clarify the neurophysiological correlates of dyslexia must require effortful, nonautomatic engagement of brain functions.[22] To test this hypothesis in our first study, we recorded dyslexic subgroups and normal peers reading at two levels of difficulty: 1) at independent reading level, where accuracy is at least 97 percent, (i.e., miscalling no more than 3 out of 100 words), and 2) at frustration level, where accuracy is below 90 percent. We found that the easy

reading level did not distinguish dyslexics from normal readers; however, the frustration level task resulted in a number of significant differences in areas predicted by our theory of differential deficits associated with each subtype.[11]

Gundersen Remediation Program

Concurrent with our research on the biological correlates of dyslexic subtypes, we completed a series of treatment studies designed 1) to identify the mechanisms of change in treatment of dyslexic children with different patterns of neurocognitive deficits (dysphonetic and dyseidetic dyslexia), and 2) to develop prognoses for response to treatment, to aid in diagnosis and management of children with neurobehavioral disorders. Based on the results of our neurophysiological studies, we expected dysphonetic and dyseidetic children to respond differently to treatment techniques emphasizing different neurocognitive processing abilities.

Our hypothesis was that emphasizing intact learning functions while circumventing processing deficits would result in optimal progress. We expected aptitude-treatment interaction effects according to the processing requirements of different reading programs. For example, phonetically-based reading programs (e.g., Orton-Gillingham, DISTAR)* were expected to hamper reading development for dysphonetic children who are phonologically impaired due to neurological deficits, while facilitating the progress of dyseidetic children who are presumed to have normal phonetic analysis function.

Our studies were designed to overcome the deficiencies of previous treatment research, particularly the lack of generalizability from clinic-referred samples and laboratories to educational treatment settings.[23,24] To ensure generalizability of findings, our studies were implemented in school settings rather than the laboratory, with a strong theoretical rationale. All second, third, and fourth grade children in two participating schools were screened for reading failure. Those identified as dyslexic were further subtyped as dysphonetic or dyseidetic and randomly assigned to: 1) a phonetically-based program (Orton-Gillingham Project Read or DISTAR); or 2) a language experience approach using the initial teaching alphabet (ita).†

Both DISTAR and Orton-Gillingham Project Read are prominent treatment choices for remediation of dyslexia. Their emphasis on phonics matches the presumed phonetic strengths of dyseidetic children and circumvents their difficulty with visual memory. Although considerable research supports the use of the ita for early acquisition of reading and writing, we found little reference to its use in treatment of dyslexia. However, we hypothesized that it would facilitate reading development for dysphonetic children because it reduces the phonological processing requirements for decoding words and eliminates the irregular spelling patterns of our written language.

Our early treatment studies using these reading programs are briefly summarized to illustrate findings pertinent to our hypothesis that children with different kinds of dyslexia respond best to treatment programs matching their intact processing characteristics. In each of the studies reviewed here, there were no significant differences between groups on preintervention variables of age, grade placement, IQ, or reading and spelling performance. Children were randomly assigned to small groups consisting of three or four per group. Treatments lasted for 33 weeks, 4.5 hours per week, for a total of 149 hours of instruction. Remediation specialists were unaware of subtype membership or expected response to treatment. In addition, during the first study, remediation specialists exchanged groups at mid-year in order to control for teacher variables.

In the first study, three dysphonetic and three dyseidetic children participated in the ita-language experience treatment program, while five dysphonetics and two dyseidetics were assigned to the DISTAR group. As expected, dysphonetics in the ita group scored significantly higher than dysphonetic peers in DISTAR when tested with curriculum-based reading tests (P=0.02). Unexpectedly, dyseidetics in ita scored significantly higher than dyseidetics assigned to DISTAR on ability to read accurately (P=0.004). Further, dysphonetic children in DISTAR made significantly greater gains in reading accuracy than dyseidetics assigned to the same program (P=0.0006).[23,25] It had been expected that emphasis on phonetic skills would hamper reading acquisition by dysphonetic children while facilitating progress for dyseidetics. The small number of children in each group prompted us to continue treatment studies before considering possible explanations for these findings.

In the second study, eleven dysphonetics and three dyseidetics were assigned to the ita group, while three dysphonetics and three dyseidetics participated in the Orton-Gillingham Project Read program. Dysphonetics in ita demonstrated statistically significant gains in reading fluency (curriculum-based reading tests) compared with dysphonetics in the Orton-Gillingham program (P=0.03). There were no significant dyseidetic differences by treatment program. Again, small numbers of subjects in each treatment group precluded drawing of conclusions.

In order to increase sample size and the confidence with which conclusions could be drawn, multiple year data were compiled by subtype and treatment. This yielded fifteen dysphonetics who had been assigned to ita for their first year of treatment, six in Orton-Gillingham, and six in DISTAR. For dyseidetics, five had participated in the ita program during their

*The Orton-Gillingham remedial reading program was originally developed by educator Anna Gillingham in conjunction with Dr. Samuel Orton, a neuropsychiatrist who developed influential theories of brain organization in dyslexia and methods for remedying such deficits. Programs based on their work emphasize seeing, saying, and tracing letters while sounding out words, and analysis of the linguistic, rule-based patterns of our language. Their method is used in numerous clinics and educational settings concerned with remediation of dyslexic children and adults.

The Orton-Gillingham Project Read program used in this research study contains detailed protocols for each lesson sequence. (Greene V, Enfield ML. Project Read. Bloomington Public Schools, Bloomington, MN.)

The DISTAR reading program is based on sequential, carefully structured presentation of letter sounds until mastery is achieved on each. Blending individual sounds to decode phonetically-regular words and "saying it fast" to develop automatic word recognition is a major component of the program, which provides detailed scripts for remediation specialists working with children. (Engelmann S, Bruner E. DISTAR Reading. Science Research Associates, Inc., Chicago, 1984.)

†The initial teaching alphabet (ita) is a set of 44 symbols that represent the 44 sounds of spoken English. While most symbols are the same as traditional letters, e.g., "b", "g", "a", others are unique representations of the sounds not captured by our traditional alphabet, e.g., "æ" for the long "a" sound. Ita was originally designed to be used with beginning readers in order to facilitate acquisition of reading and writing. Special applications of ita include teaching English as a foreign language and remediation of language-impaired children in clinical settings. (Downing J. Initial Teaching Aphabet Foundation. The B C Teacher 1967; 47:100-5.)

first year in the project, three in Orton-Gillingham, and four in DISTAR. There were no significant group differences on preintervention comparisons of chronological age, grade placement, receptive vocabulary, and reading measures used as outcome variables.

Post-treatment comparisons for dysphonetics revealed significantly greater gains for those in the ita treatment compared with DISTAR on untimed word reading (WRAT-R* Reading, P=0.02) and spelling (WRAT-R Spelling, P=0.02). There were no significant treatment differences for dyseidetic children. Program comparisons revealed that children in the ita program, regardless of subtype, made significantly greater progress than those in DISTAR on Curriculum-Based assessments (P=0.05), on WRAT-R Reading (P=0.02), and on WRAT-R Spelling (P=0.005). These results were especially interesting in light of the testing and treatment design. All pre- and post-tests required children to read and spell in the standard alphabet while the ita program had featured use of the initial teaching alphabet for all reading and writing instruction.

Although too few dyseidetic children participated in these studies to draw subtype-treatment conclusions, the data supported the hypothesis that children with dysphonetic dyslexia respond differently to treatments emphasizing different processes.[23,25] In addition, examination of teacher logs and student data charts suggested that children in the ita-language group responded to different lesson presentations in ways supporting our subtype-treatment interaction hypotheses.

Based on these observations and results, our research challenge was to design ways to quantify and measure responses to individual components of reading programs rather than global measurement of progress within a particular reading program containing many elements. In our current study we are using a multiple-baseline, repeated measures design, with each child exposed to four different reading-spelling treatments in order to investigate the specific components of the ita-language experience that result in optimal progress for children with different kinds of dyslexia (dysphonetic or dyseidetic) and at different levels (elementary or middle-high school). This design, in which each child serves as his own control, is expected to increase the confidence with which subtype-treatment interaction results can be interpreted due to the large number of children available for analysis and to the control of teacher, child, and history influences on outcome.

Gundersen Reading Study

Early identification of children at risk for dyslexia is important in light of evidence that early intervention decreases underachievement in later school years.[26-28] For example, Strag[28] reported that of the children identified in first and second grade, 82 percent were brought up to their normal reading level. For those not identified until fifth grade or later, only 10-15 percent were helped. Despite the importance of early identification, current identification procedures generally result in years of school failure before the exclusionary criteria and requisite discrepancy between aptitude and achievement have been met.

*The Wide-Range Achievement Test-Revised (WRAT-R). Jastack Associates, Inc., Wilmington, DE, 1984.

Given the importance of early identification and intervention, in 1988 we began a five-year research study designed 1) to develop a valid and reliable group screening battery to identify kindergarten children who are at risk for reading failure, and 2) to determine effective early intervention programs for children with particular patterns of pre-reading deficits identified via the screening battery. In cooperation with 26 Minnesota and Wisconsin school districts, we initiated the Gundersen Reading Study, believed to be the largest epidemiological study of reading disability in the United States. The public and parochial school districts participating in the study comprise an ideal laboratory for studying reading development longitudinally because of the exceptional stability and homogeneity of the student population, and the mix of urban and rural children representing all socioeconomic levels.

This large epidemiological study has resulted in development of a kindergarten screening program for identification of children at risk. *The Gundersen Kindergarten Screening Battery* (GKSB), which assesses phonological, semantic, syntactic, visual-motor-perceptual, and alphabetic knowledge, has been developed and used with four cohorts of 5317 children who are being followed across the elementary years in which reading develops. The purpose of the GKSB is to predict who are at risk for reading failure, when and how they will fail, and how to intervene in order to prevent or ameliorate reading failure. Predictive validity studies indicate that the battery is significantly correlated with reading achievement, and that its usefulness in identifying children who will fail in reading is even greater at third grade level than at first or second.[29]

Analyses of study data have resulted in significant findings pertinent to pediatric and educational practice regarding young children. For example, initial analyses of children screened in kindergarten and followed through third grade indicate that widely-held beliefs related to age-of-entrance and gender in relation to reading achievement are not valid. Many educators believe that young children, and especially young boys, are at greater risk for reading failure and would benefit from delayed school entrance or retention in kindergarten.[30]

Our analysis of the effect of age of school entrance, gender, and their interaction on reading achievement at the end of first grade (n=1215), second grade (n=1141) and third (n=1037) revealed that these variables and their interaction accounted for less than 1 percent of the variance in reading scores. The importance of this study is reflected in the finding that the GKSB, a set of simple kindergarten screening tasks, predicted 36-44 percent of the variance in reading achievement one to three years later, while age of school entrance and gender predicted less than 1 percent of the variability in reading achievement at the same grade levels.[31]

These results are especially relevant to pediatricians asked to advise parents on their child's readiness for kindergarten. Given the enormous amount of time and energy spent on the issues of gender and age in relation to school failure, it appears important for pediatricians and developmental specialists to take an active role in dispelling the myths of immaturity based on these erroneous assumptions.

Our findings also suggest the need for pre-kindergarten screenings of specific precursors to school success in addition

to the general developmental measures commonly used in pediatric practices. Pre-school screenings could be used in a behavioral pediatric setting to advise parents regarding stimulating experiences for their child prior to and concurrent with formal schooling. The GKSB is currently being adapted for pediatric practice in order to provide profiles of language, linguistic, visual-motor, and visual-perceptual skills in pre-kindergarten children.

Synthesis of Research Findings

The Gundersen Medical Foundation dyslexia projects reviewed here illustrate the necessity and benefit of examining the complex disorder of dyslexia from different aspects simultaneously and within a developmental, longitudinal framework. The synergism of our QEEG/ERP and treatment projects has led to advances in our understanding of how the brain processes linguistic information, how these processes break down in children with different types of dyslexia, and how to successfully intervene to develop accurate and fluent reading. An example of this synergism of medical and educational research is our reconceptualization of Boder's dyseidetic subgroup. Boder theorized that these children were normal in decoding skills and deficient in visual functions mediated by the right hemisphere, while our EEG and treatment results jointly suggested overengagement in left hemisphere mediated decoding function. Our theory of linguistic etiology for this subtype has integrated the original Boder with contemporary neuropsychological theory and biological studies.[4,10,25]

Further research is needed in order to determine the ultimate value of our findings to pediatric and educational practice. We are particularly interested in combining the longitudinal reading study with our QEEG and treatment study in order to identify groups of kindergarten children at risk and a cohort of normally-developing pre-readers. By following those groups across the first three grades of school with yearly individual assessment of developmental, physical, attentional, academic, neuropsychological, and neurophysiological parameters, we hope to establish norms for clinical procedures leading to early diagnosis, accurate prognoses, and effective treatment of children with dyslexia.

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