Procedural Deficits in Learning Disorders: A View Beneath the Verbal-Nonverbal Dichotomy

Dana Chidekel, PhD, ABPdN, ABN
and Deborah Ely Budding, PhD, ABPdN, ABN

There is a natural marriage between pediatric neuropsychology and educational therapy. Both disciplines accept the fact that – indeed, exist because – there are many possible explanations for the "same" academic problem. Inherent in our work is the challenge associated with discovering the roots of a child's particular limitations, and crafting interventions specific to his dynamics to permit him to gain mastery. Educational therapists plot the course of the treatment and accompany a child on the journey. Neuropsychologists provide a map of the terrain.

Neuropsychology has evolved and continues to do so. Having moved past the historical era of the lobotomy, when the frontal cortex was seen as expendable, and having subsequently abandoned the view of the right hemisphere as a "silent hemisphere" whose main role was to ensure that the skull was symmetrical, brain scientists have spent the last decade expanding our understanding of the roles of the left and right hemispheres and the frontal and posterior cortex in perception, reasoning, executive functioning, decision-making, learning, and attention. In keeping with the focus on the brain cortex, developmental reading and writing disorders, as well as "nonverbal" learning disorders, have been largely conceptualized along right versus left hemisphere and frontal versus posterior cortical dimensions as well. While the cortex has been focal in neuropsychology, structures below the cortex, including the basal ganglia and the cerebellum, had been considered mainly as regulators of movement if they had been considered at all. In children's brain development, as it is now understood, cortical functions that are initially fairly minimal, relative to the activity occurring below the cortex, become more prominent over time. This centrally important role of the vertical progression of brain development has been minimized by this cortical approach (Ansari, in press).

Until now. A growing body of research highlights the critical role of these deeper structures in regulating subcomponents of attention, executive function, social behavior, emotional function, and learning (Koziol & Budding, 2009). To the right-left concept of brain organization, we now add the more vertically oriented cortical-subcortical view. Rather than casting verbal-nonverbal behavior as the central organizing principle of brain function, this cortical-subcortical view highlights the continuum between behaviors that are performed automatically versus those that require effortful, conscious, higher-order control. Automatic behaviors can be understood as procedures that are stored within and executed as part of a procedural memory system. Controlled behaviors are, at least initially, more akin to individual events. What initially requires higher-order control can become a procedure with repetition and practice (or with one emotionally intense exposure, such as when a single trauma establishes a post-traumatic stress reaction). Every motoric, cognitive and emotional behavior we engage in can be placed on the automatic-higher-order control continuum.

Examples of behavior on the automatic side of the continuum include the physical act of walking, starting a car, brushing our teeth, spelling our own name, driving a familiar route to work, having a gut feeling about a situation, shaking someone's hand, recognizing the numeral "2", and taking natural turns in a conversation. On the other end of the continuum, examples of controlled behaviors include walking on uneven ground, spelling someone else's name, balancing a checkbook, writing with our nondominant hand, suppressing tears, driving in England, figuring the value of a number with 12 place-values, and eating with an unfamiliar utensil. Subcortical structures, in reciprocal relation with the cortex, regulate how much conscious effort a particular task demands versus how much of it can be performed more automatically. Adjustments in this ratio are made moment by moment, in the context of different demands. Adaptive function depends upon these systems. We conserve resources by releasing automatic behavior quickly, in familiar circumstances, so we have cognitive resources to spend when we meet novel problems that need to be addressed more deliberately. The former are efficient; the latter allow us to adapt to, and learn from, new experiences. Attuning the intensity of the response we generate to the context and establishing an effective rhythm with which we engage with material allows us to spend our energies economically.

The "dual-system" automatic-controlled view adds needed dimension to our understanding of a variety of learning problems. Children who naturally develop fluent, competent academic skills are those for whom the interplay between automatic and effortful modes of function is well balanced, while many children with learning challenges do not regulate these systems fluidly. If automatic procedures cannot be established effectively, the "simple" aspects of academic demands that others execute "without thinking" require disproportionate cognitive effort and energy to do. A child who does not automate motor sequences necessary for the fluid production of letters can write, but the physical act of writing will drain physical and cognitive energy and will take time. A child with adequate phonemic awareness who cannot automate sight words can read, but not fluently. Children who have not automated math facts can calculate them, but at a cost to efficiency, which is compounded because a lack of automaticity, or procedural deficits, often extends to difficulty automating math procedures as well.

When such problems exist foundationally, "something's gotta give." Some children maintain a fast pace and make small errors. Others, dedicated to preserving accuracy, go slowly and in so doing, burden working memory and sustained attention.

They are likely to get lost in the material and may simply give up. By neuroanatomic definition, these are generally the same children who demonstrate difficulties with executive function and regulation of multiple subcomponents of attention, because it is within these same frontal-subcortical networks that the capacity to sustain attention, inhibit the impulse to act and to respond to distraction, engage working memory, and shift attention are mediated. This understanding of brain function muddies the distinction between many specific learning disorders, executive function problems, obsessive-compulsive disorder, ADHD, and a variety of other psychiatric disorders that affect social skills and judgment. Problems in frontal-subcortical circuitry and the associated poor regulation between automatic and effortful processing, and regulation of the rate, rhythm and force of behavior is the common soup from which all such problems arise.

With this framework of understanding, we can examine familiar categories of learning disorders with a fresh eye and look at familiar phenomena from a new perspective.

"Verbal" Learning Disorders

Reading and writing can be understood as extensions of the language system (Mann, 2003). Whereas an early view of the brain cast language as a "left hemisphere" function, this view was expanded as researchers appreciated that prosodic and pragmatic aspects of language involved a significant right hemisphere contribution. To this we can add more recent views of the language system that take into account the vertical organization of the brain. Michael Ullman's Procedural/Declarative Model portrays language function as separable into a mental "lexicon" on one side of the continuum, and computational "mental grammar" on the other (Ullman & Pierpont, 2005).

The "lexicon" is associated with the declarative memory system and encompasses all words, facts, and other concrete and abstract aspects of language, cultural idioms ("He's a real pain in the neck"), and non-rule-based word forms ("thought" instead of "thinked"). The rule-based "mental grammar" system is associated with the procedural memory system. It guides the ordering or sequencing of regular and predictable aspects of language—particularly grammar—and allows us to combine words to make complex representations and to interpret the meanings of very complicated forms of language, even if we have not seen or heard them previously. For example, "The spong plicked the golb" is immediately recognized as something performing an action on something or someone else, even though the words are "meaningless." If a word form has not been encountered before (e.g., "ate" instead of "eated"), initially acquiring it and its proper application is mediated by the declarative system. Once encountered and automated, it is represented within the procedural system. In the developmental condition known as specific language impairment (SLI), children often have difficulty acquiring grammatical rules and are therefore forced to memorize regular and irregular forms consciously and to retrieve them consciously. Procedural deficits that underlie SLI are evident in verbal language, and in the types of errors seen in the child's written grammar and morphology. The quality of the errors a child with SLI demonstrates when she is learning to read and write also reflects problems in establishing automatic procedures. That many of these children have associated problems with aspects of motor sequencing is understandable if one sees SLI primarily as a manifestation of procedural deficits.

The cerebellum plays a role in early aspects of sequence learning, for both motor and cognitive function (Koziol & Budding, 2009). Just as it contributes to coordinating the timing of individual physical movements so they can be expressed in smooth sequences (e.g., skipping as a continuous motion, rather than as a staccato series of step-hop, step-hop, step-hop), the cerebellum play a role in coordinating multiple aspects of reading as well. Roderick Nicolson and Angela Fawcett (2007, 2009) have pioneered the conceptualization of reading development as strongly mediated by subcortical function, particularly by the cerebellum, and this concept is supported by a body of research that highlights the role of cerebellar function in various forms of dyslexia (Pernet, Poline, Demonet, & Rousselet, 2009). A dual-process approach thus looks beneath the commonly considered "auditory" and "visual" aspects of reading to appreciate the even more foundational *procedural* deficits within which the auditory and visual dimensions can be understood.

Mathematics Disorders

David Geary has written extensively about the cognitive and neurological underpinnings of developmental mathematics disorder (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007). Three main areas of deficit include retrieving math facts from semantic long term memory, executing procedures, and representing and interpreting visuo-spatial representations of mathematics material in verbal and spatial working memory. He also highlights the central importance of early number sense: an implicit understanding of the *exact quantity* of small groups of things and the symbols representing them (e.g., 3 = ***), along with the *approximate magnitude* of larger quantities (Geary, in press). Problems with number sense are associated with fact retrieval and with procedural deficits. Early number sense is considered to be an automatic, "intuitive" skill; children as young as 2 years old are able to identify one, two or three objects before they can count. Until now, mathematics education has lacked the conceptually based means to screen for early disability that has been developed in relation to reading. Nancy Jordan and colleagues (Jordan, Glutting, & Ramineni, in press) conducted a study in which they correlated number sense in first through third grades with overall mathematics achievement. They posit that early number sense plays an analogous role in math to the role that grasping letter-sound relationships plays in reading. Included in their paper is an example of the screening test they developed.

Efficient fact retrieval is foundational for later, higher-level math functioning. Problems automating math facts necessarily slow down calculation and introduce additional room for error, as do problems automating mathematical procedures. Those without math disability tend to take procedures for granted. For people with math disabilities, however, who cannot readily create and implement procedures, conscious attention needs to be directed to retrieving the procedure necessary to solve a particular problem and then to applying its steps in the correct sequence. Examples include remembering how to solve an equation presented in a columnar/vertical format versus an equation that is presented horizontally, or figuring out which principle for regrouping is appropriate for a particular equation and implementing its steps accurately.

What Do Procedural Deficits Look Like in a Student's Work?

It is important to bear in mind that learning problems with an automaticity-based component are not a function of deficits in knowledge. Rather, information that a child has acquired but has not automated can be retrieved, but at a cost. Understanding these dynamics gives us a framework to integrate what appear to be contradictory test findings.

Writing Problems

Test results from a 14 year-old right-handed boy with "writing problems" appear intact in the context of the discrete, structured demands that are made by the Woodcock Johnson Test of Achievement (Third Edition)

Spelling standard score = 97 (42nd percentile)
Editing standard score = 95 (37th percentile)
Writing Samples standard score = 103 (58th percentile)

The lack of automaticity underlying his writing ability is very apparent, however, in the context of his response to the more open-ended demands made by the Test of Written Language (Donald D. Hammill & Stephen C. Larsen), Spontaneous Writing.

> *Jon felt the air presser press agenst him from outside his starck white astronat suit. He lifted his hand agien above his head then let it swing down. Bang went the metal as it hit the moon rock the stone cracked then fell away reviling what John had been looking for, evidence.*
>
> *John put his finger to the talk boton on his radio and sayed into it, Iv got it chief."*
>
> *He let go of the botton then heard the low and gruff voise of the chief, "well done Tomson im sending the crew."*
>
> *Jon left his hammer and picked up a brush. He sweped it over the smoth coloed serface of the rock a few times, then read the word BROTHERS. It was carved into the top of the stone almost like a toumb. he wondered what it stood for and if he was relly neeling on a grave sight.*

With procedural deficits, it is not uncommon to see the same word misspelled differently in the same passage or the same sentence. Kids who "know" they should capitalize the first word of each sentence, don't. Punctuation marks are left out, misused and misused in different ways in the same composition. Letters are left out of words, transposed, reversed, or added. Run-on or fragmentary sentences may be included. Spelling may be phonetically correct yet orthographically atypical, which reflects a lack of automaticity of commonly co-occurring letter combinations.

Reading Problems

Procedural deficits affecting reading may manifest as difficulties establishing sound-symbol relationships at a level at which they can be retrieved without effort. The longer the word being decoded, the greater the strain on this system and the more likely the child will be prone to make errors. Children with procedural deficits may have difficulty establishing a sight word vocabulary for words that are frequently encountered. They may speed through reading and misapply whole word strategies, altering the meaning of text. Alternatively, they may slow down to be accurate, and in the process lose the big picture of content. If sweeping the eyes from left to right is not established automatically, cognitive energy must be spent remembering to do so or reorienting backward when text makes no sense. The process opens the way for errors, such as skipped lines. If the visual forms of "d" and "b" are not stored automatically, they will be misread.

Math Problems

Procedural deficits affecting math may manifest in a child's inability to retrieve math facts quickly, without calculating them. Math procedures, such as carrying, borrowing, deriving common denominators, and performing order of operations may be vulnerable. A child may display adequate ability to calculate math facts, but may make math fact errors on an equation with multiple steps. Alternatively, math facts may be calculated accurately, but the student may lose track of her place in the equation and miss a step or two, or repeat a step. When performing long division, a student may have to add columns of numbers as she tries to figure out the answer, instead of performing the more efficient procedure to do so. Adding mixed numbers, the student may fail to include the whole number in the final operation. The strain of doing a page of equations with these limitations may lead students to fail to attend to signs of operation and to make errors on this basis. A number may be carried in a multiplication problem, but instead of adding it to the sum of the next operation, the student may multiply by the number that was carried instead, such as in the case of these math problems attempted by a 10-year-old girl.

$$\begin{array}{r} 2 \\ 1\,4 \\ \underline{\times\,6} \\ 124 \end{array} \qquad \begin{array}{r} 2 \\ 1\,3 \\ \underline{\times\,7} \\ 141 \end{array}$$

When the examiner rewrote the equations on fresh paper and asked her to verbally describe the process of her problem solving (i.e., engaging her conscious, effortful processing), she did not make the same errors.

Non-Verbal Learning Disorder

Nonverbal learning disorder, or NLD, is not officially recognized as a disorder by the Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV), but rather is used to describe a combination of academic, functional and social behaviors that cluster broadly around problems using spatial information and relative "strengths" in language. As conceptualized by Rourke (1989), people with NLD present with intact and even strong verbal skills, though they almost uniformly demonstrate problems using language despite their large vocabularies and high scores on verbal tests. Language use as well as prosody and language pragmatics are often misattuned to context. Asked, for example, a "verbal" test item such as "How are a parakeet and an eagle alike?" a child thought to have NLD may generate something like the following: *They are almost exactly alike because they are both animals that exist. They evolved from other animals. It's possible that Godzilla could exist, or it's possible that life forms like E.T. exist.* Linguistic overshooting of this nature as well as the atypical prosody that is a feature of NLD are linguistic analogs of dysmetria (the inability to control accurately the range of movement in muscular acts with resultant overshooting of a mark); dysmetria is noted on the motor examinations of individuals with known cerebellar problems, (such people cannot match the rate, rhythm and force of responses to the neurologist's demand).

People described as having NLD demonstrate trouble adapting to novel circumstances; placing events in order; understanding cause-effect relationships; matching vocal, emotional and cognitive "tone," regulating emotional response; understanding math and the content of what they read; organizing their writing; generalizing material across domains; and negotiating multiple executive function demands requiring decision-making, planning, initiating, prioritizing, controlling impulses, self-monitoring, and self-correcting. These individuals often have a history of motor development problems and continue to manifest poor coordination and balance, and poor graphomotor skills.

The careful reader will note that people meeting criteria for multiple DSM-IV psychiatric and neurodevelopmental disorders—including ADHD, mood and anxiety disorders, disruptive behavior disorders, learning disorders, and autism spectrum disorders—demonstrate a number of the behaviors that are criteria for NLD. In *Tigers, Too*, Marilyn Dornbush and Sheryl Pruitt (2009) address procedural learning problems commonly associated with neurodevelopmental disorders such as ADHD, obsessive-compulsive disorder, and Tourette's syndrome. The NLD "diagnosis" as such is simultaneously over- and underinclusive. While NLD has been considered a manifestation of cortical right hemisphere and/or white matter connectivity problems, the dual-process approach that highlights the vertical organization of brain systems provides a more parsimonious explanation of the NLD strengths and weaknesses as outgrowths of poor mediation between automatic and controlled processing and poor coordination of the rate, rhythm and force of behaviors generated in a particular context.

The Educational Therapist's Role

To be successful in school, and in life, children need automatic procedures on which they can rely to approach academic and organizational tasks. Since educational therapists help children develop procedures they need to acquire content and to demonstrate what they have learned, it would seem that this dual-process approach represents a natural extension of the ways educational therapists think and approach their work. Codifying what may be intuitive concepts is valuable insofar as it can help professionals think more systematically about what they do and can provide an orienting, brain-based way of organizing this information.

When children's problems are identified and explained to educators in this manner, compelling arguments can be made in Student Study Teams (SST), Section 504 and IEP meetings regarding the need for accommodations and different types of supportive services such as occupational therapy, physical therapy, speech and language services, social skills training, and alternative learning placements. A strong neuropsychological assessment that outlines the issues is invaluable to this end. Apprehending procedural deficits can inform the need for rote repetitive approaches to learning, such as drilling with Kumon materials (Kumon Publishing North America, Inc., Teaneck, NJ 07666) and rhyming card games. Systematic approaches to treating discrete aspects of learning disorders are also being developed that are founded on an understanding of these aspects of brain function. The RAVE-O program for reading fluency (Katzir, Kim, Wolf, Morris, & Lovett, 2008; Wolf, Miller, & Donnelly, 2000) and aspects of the Lindamood Bell System (Gander Publishing, San Luis Obispo, CA 93401) are just two examples. Apprehending procedural deficits, along with the limitations in working memory and sustained attention that are so often co-morbid, can inform the child's need for parts-to-whole approaches to learning concepts, for different types of scaffolded reading approaches to facilitate comprehension, and for strategies to organize writing that reduce the demand for accurate grammar and spelling.

Many educational therapists may already be incorporating these approaches and using multiple interventions to support the development of procedures. Being able to explain the underlying neurodynamics to a student (at a level of complexity appropriate to her age and capability), however, can recruit the child to be a more active participant in the therapeutic process. Teachers may feel more compassionate and patient when they realize that the child's demonstrated limitations in class are not a function of laziness or ill will, and they may learn new strategies to teach such children. Being able to explain these dynamics to parents may help them understand why educational therapy is not a quick fix, and may help them appreciate the differences between the roles of an educational therapist and a tutor. Also, if parents reframe their understanding of what a child *won't* do with an understanding of what he *can't* do, they can stop taking a child's difficulties personally and understand what the child reasonably can be held accountable for. When a parent's attribution of a child's difficulty shifts from seeing him as willfully lazy or resistant to seeing a struggle inviting compassion and help, the child's future relationships to self, to others, and to a lifetime of learning are transformed.

References

Ansari, D. (in press) Neurocognitive Approaches To Developmental Disorders of Numerical and Mathematical Cognition: The Perils of Neglecting the Role of Development. *Learning and Individual Differences*, Retrieved 21 June, 2009, from http://198.81.200.2/science/journal/10416080

Dornbush, M. P. & Pruitt, S. K. (2009). *Tigers, Too: Executive Functions/Speed of Processing/Memory: Impact On Academic, Behavioral, and Social Functioning of Students With Attention Deficit Hyperactivity Disorder, Tourette Syndrome, and Obsessive-Compulsive Disorder: Modifications and Interventions.* Atlanta, GA: Parkaire Press.

Geary, D. C. (in press) Mathematical Disabilities: Reflections on Cognitive, Neuropsychological, and Genetic Components. *Learning and Individual Differences.* Retrieved October 25, 2009, from http://198.81.200.2/science/journal/10416080

Geary, D. C., Hoard, M. K., Byrd-Craven, J., Nugent, L., & Numtee, C. (2007). Cognitive Mechanisms Underlying Achievement Deficits in Children with Mathematical Learning Disability. *Child Development*, 78, 1343 - 1359.

Jordan, N. C., Glutting, J., & Ramineni, C. (in press) The Importance of Number Sense to Mathematics Achievement in First and Third Grades. *Learning and Individual Differences,* Retrieved July 21, 2009, from http://198.81.200.2/science/journal/10416080

Katzir, T., Kim, Y. S., Wolf, M., Morris, R., & Lovett, M. W. (2008). The Varieties of Pathways to Dysfluent Reading: Comparing Subtypes of Children With Dyslexia at Letter, Word, and Connected Text Levels of Reading. *Journal of Learning Disabilities*, 41, 47 - 66.

Koziol, L. F. & Budding, D. E. (2009). *Subcortical Structures and Cognition: Implications for Neuropsychological Assessment.* New York: Springer.

Mann, V. A. (2003). Language Processes: Keys to Reading Disability. In H. L. Swanson, K. R. Harris, & S. Graham (Eds.), *Handbook of Learning Disabilities* (pp. 213 - 228). New York: Guilford Press.

Nicolson, R. I. & Fawcett, A. J. (2007). Procedural Learning Difficulties: Reuniting the Developmental Disorders? *Trends in Neuroscience,* 30, 135 - 141.

Nicolson, R. I. & Fawcett, A. J. (in press). Dyslexia, Dysgraphia, Procedural Learning and the Cerebellum. *Cortex,* Retrieved October 9, 2009, from www.cortexjournal.net/article/PIIS0010945209002615/fulltext

Pernet, C. R., Poline, J. B., Demonet, J. F., & Rousselet, G. A. (2009). Brain Classification Reveals the Right Cerebellum as the Best Biomarker of Dyslexia. *BMC Neuroscience*, 10, 67.

Rourke, B. P. (1989). *Nonverbal Learning Disabilities: The Syndrome and the Model.* New York: Guilford Press.

Ullman, M. T. & Pierpont, E. I. (2005). Specific Language Impairment Is Not Specific To Language: The Procedural Deficit Hypothesis. *Cortex*, 41, 399 - 433.

Wolf, M., Miller, L., & Donnelly, K. (2000). Retrieval, Automaticity, Vocabulary Elaboration, Orthography (RAVE-O): A Comprehensive, Fluency-Based Reading Intervention Program. *Journal of Learning Disabilities*, 33, 375 - 386.

Research Watch…
The National Children's Study

"The environment is a powerful determinant of health and disease especially for children" (Landrigan, 2009) In developing nations, while infectious diseases and infant mortality decline, and life expectancy increases, *chronic* diseases become increasingly prevalent. Children are particularly vulnerable to environmental exposures to toxic chemicals. The US Department of Health and Human Services, the National Institutes of Health, the Centers for Disease Control and Prevention, and the US Environmental Protection Agency have joined together to develop and implement the largest longitudinal study to date of children from birth to age 21, their families, and their environment. The National Children's Study will enroll approximately 100,000 children, recruited from preconception or early pregnancy, and will examine environmental and genetic influences on human growth, development, and health outcomes. The study will be conducted at 105 facilities across the country. At this time, pilot studies are being conducted at vanguard study centers. The full study is scheduled to begin this year (www.nationalchildrensstudy.gov).

Reference

Landrigan, P. J., (2009, November). *Children's Health and the Environment: the Problem and the Solution*. Paper presented at the Massachusetts School of Professional Psychology, Boston, MA.