PEDIATRIC NEUROPSYCHOLOGICAL TESTING: THEORETICAL MODELS OF TEST SELECTION AND INTERPRETATION

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General Considerations

Neuropsychology is defined as the study of brain-behavior relationships. The neuroanatomic underpinning for all behavior is the nervous system, and in neuropsychology, the primary substrate for the study of behavioral organization is the brain. Neuropsychology should focus upon how cognitive, emotional, social, sensory, motor, and self-regulatory, executive behaviors are organized within the brain. However, neuropsychology has historically focused primarily upon evaluating cognition (Lezak, 2004). This is the case for three reasons. First, neuropsychological assessment is traditionally rooted in evaluating persons with documented brain impairment. These patients typically feature cognitive impairment as prominent aspects of their symptoms. Second, many types of cognitive functions can be readily conceptualized through tests of learning, memory, and problem-solving, and as such, cognitive functions have traditionally been easier to identify and measure than other brain-related behaviors. Functions such as emotion, affect, and motivation which can affect cognition yet fall outside the strict cognitive domain have proved difficult to operationalize, identify, and measure through direct testing processes. Emotional and motivational functions have often been assessed either informally or through the application of various observational methodologies. Third, during the course of a relatively brief neuropsychological assessment, the opportunity for even observing subtle impairment in emotional and motivational control is limited.

Neuropsychology's apparent emphasis upon cognitive skill sets need not minimize the role of the brain in directing emotional, motivational, and social/interpersonal behaviors. In fact, recent developments in multiple branches of neuroscience have underscored the importance of these aspects of brain-behavior relationships that have been elusive for traditional applied neuropsychology (Barnes et al., 2007; Hare et al., 2008; Lamm et al., 2007). Nevertheless, cognition does not operate in isolation, a caveat that has particular relevance for developmental disorders. Some recently developed pediatric neuropsychological instruments have made attempts to include emotional/social variables, but these aspects of evaluation remain in their infancy (Korkman et al., 2007). Therefore, this brief review will focus upon cognitive functioning.

Much of our current understanding of brain-behavior relationships has resulted from studying adult patients with documented brain lesions. Evaluating patients with various pathological brain conditions has elucidated our knowledge of how brain structure contributes to function. Much of this understanding of brain function concerns cortical-behavior relationships. While there are many theoretical reasons for this cortico-centric preoccupation, one practical clinical reason concerns the fact that cortical pathologies can be common in adult, and for that matter, certain child populations as well. For example, traumatic brain injury, neoplasm, and hemorrhagic events very frequently involve cortical tissue changes. Over the past 15 years or so, however, it has become apparent that subcortical brain regions also contribute to cognition. In addition, the extended basal forebrain (basal ganglia) and cerebellum play essential roles in emotional, motivational, and social functioning (Koziol & Budding, 2009). This has considerable relevance for developmental pathologies.

In pediatric neuropsychology, a critical additional feature to be considered concerns developmental brain maturation (Bernstein, 2000; Munakata et al., 2004). Simply put, a child's cognition, emotional maturation, and capacities for self-regulation and control, all change over time so that the child's repertoire of behavior is different at different ages. There are important differences in maturation across gender as well (Overman et al., 1997). Cultural background, socio-economic status, race, and various environmental factors are also variables to be considered (Buckhalt et al., 2007; Surkan et al., 2007). Further, research is ongoing in relation to how and when various capabilities develop (Gervain et al., 2008). This is not the case for a fully developed adult, although many of the previous factors also apply and have been discussed at length elsewhere. While adult neuropsychological assessment might be analogous in some ways to taking a photograph of a "still image," pediatric assessment might in relation be conceptualized as attempting to photograph an object "in motion." Therefore, while demographically-based standards play an important role in neuropsychology per se, developmentally referenced standards become important for assessing child and adolescent populations (Baron, 2004).

However, pediatric neuropsychological assessment largely has roots in adult neuropsychology. In fact, many neuropsychological tests used with child populations essentially comprise downward extensions of adult tests. These tests were initially developed in relation to adult patient populations instead of being constructed specifically for use with children. Because of the information processing characteristics of certain tests, such as the Rey Complex Figure (Meyers & Meyers, 1995) and Digits Backward (Wechsler, 2003), for example, the complexity of the task might not be sensitive to developmental issues for some ages and therefore have limited clinical interpretive value depending upon when it is administered (Anderson et al., 2001; Ofen et al., 2007; Sowell et al., 2001).

This chapter has several purposes. We will first review issues related to decision-making for appropriate test selection in pediatric populations. We will then examine common assumptions made in relation to evaluating certain abilities and skills. A third area of discussion will involve current methodologies for test interpretation. Fourth, proposed alternatives to the cortico-centric model of cognition will be illustrated with a methodology that holds promise for a more integrated view of brain-behavior relationships in the developmental pediatric population. Finally, we will present proposed standards for more consistent evaluations and findings among neuropsychologists with application to both cortico-centric and cortical-subcortical approaches to test interpretation.

Test Selection: Fixed Batteries

Perhaps one of the most basic practical considerations in an evaluation concerns the issue of test selection. There is considerable truth to the statement, “you can only find what you look for.” This saying is quite appropriate to apply to the decision of using a “fixed” or a “flexible” test battery. Arguments as to whether one or the other is “better” or even allowable have long grown stale and are outside the concerns of the current undertaking of this chapter. Both of these types of testing approaches have advantages and disadvantages, and neither methodology presents a guarantee against making either false positive or false negative diagnostic errors. Both fixed and flexible evaluation methodologies are subject to the possible errors of misdiagnosis. In addition, either methodology can provide an examiner with a false sense of security. We believe that understanding the advantages and disadvantages involved in test battery selection helps to minimize the chances of diagnostic error.

A fixed battery of tests is composed of a standard set of instruments that has been validated through extensive research on normal controls and various patient populations. Perhaps the best known example of this type of battery is the Halstead-Reitan Battery (HRB). While originally standardized for adult use, a downward extension was developed for use with children of school age from 9 through 14 years of age and an additional version was developed for use with children from 5 through 8 years of age (Reitan, 1979; Reitan, 1984; Reitan & Wolfson, 1992). It was never entirely clear as to whether or not this “stand alone” battery of tests held any significant advantage for diagnosing “brain damage” as compared to the WAIS-R (Kane et al., 1985). The Luria Nebraska was also standardized in a version for children (Golden et al., 1980; Golden, 1987). Over a decade later, the Developmental Neuropsychological Assessment for Children (NEPSY) was published (Korkman et al., 1998). This battery of tests represented the first systematic attempt to develop and apply tests that evaluate the cognitive, sensory, and motor functioning of children aged 3 through 12 years. This battery of tests is now in its second edition, which includes an upward extension of certain subtests through the age of 16 years (Korkman et al., 2007).

Perhaps the biggest advantage of using a fixed battery of tests concerns its standardization. In the case of the NEPSY, all the tests in the battery were standardized using every subject in every age group, consisting of age ranges defined in six-month intervals. This standardization allows for a variety of direct test score comparisons for all of the functions that the battery measures. When using a flexible battery with tests individually chosen by an examiner, the standardization samples for the different tests are obviously different, which can constitute an unknown source of variability for test interpretation (Wong, 2006). Therefore, the homogeneous standardization sample of the fixed battery represents a distinct advantage, particularly in relation to evaluating cases of known, localized cortical lesion.

A fixed battery approach can also seem to have advantages for the novice examiner who is gaining experience. A flexible battery approach requires a solid knowledge of functional neuroanatomy and clinical conditions, an understanding of how patients behave with tests, and of how tests “behave” with various patient populations. For example, consider an evaluation of the attentional domain. The experienced clinician understands that attention is not a monolithic entity, but instead comprises a group of related functions and processes (Mirsky & Duncan, 2004). Assessing these functions requires administering a variety of tests. A fixed test battery, such as the NEPSY series, at least provides an assessment of those attention-related processes considered part of the attention domain as operationally defined for that particular battery. However, this type of assessment might not include an in-depth assessment of attention functions as they are currently defined in contemporary neuropsychological theories (Cohen et al., 1998; Mirsky, 1996; Mirsky & Duncan, 2001; Posner & Petersen, 1990).

The previous example brings us to the next topic: namely, the weaknesses of fixed battery approaches. For example, fixed batteries might be organized around the theoretical orientation of the author of the test battery. This might result in a battery of tests that over-emphasizes assessment of some functions while under-emphasizing the evaluation of other functions. Some cognitive domains thus might not be evaluated comprehensively. For example, consider the domain of memory, another functional process that is certainly not a unitary entity. Some fixed test batteries assess memory through the administration of a word list learning task. The word list learning task might include an immediate recall trial, several learning trials, as well as short and long delay free recall trials. However, a recognition trial might be omitted. This omission is a critical weakness. While word list learning tasks can be used to assess the integrity of the medial temporal lobe memory system, this system is essentially a recognition memory system.

Voluntary, or free recall, conditions assess **access** to that system, but voluntary recall trials do not adequately evaluate information storage or retention. To evaluate what was retained after learning trials, a recognition condition becomes absolutely necessary

(Squire, 2004; Squire & Shimamura, 1996). Comparing a recognition trial with a long delay free recall trial allows for the critical differentiation between retention and access. If inferences are based solely upon free recall trials without making this important distinction, interpretive statements about the functional status of “memory” can be highly misleading. This differentiation has vast implications for management and treatment. Therefore, the fact that any given fixed battery might *claim* to assess all necessary cognitive domains does not mean that any given domain is evaluated comprehensively or even sufficiently. Failing to consider this issue can lead an inexperienced examiner to develop a false sense of self-confidence about administering a comprehensive evaluation while actually making a diagnostic error. Most ready-made test batteries contain these types of “quirks” that can only be recognized if an evaluator has a sound understanding of brain-behavior relationships *and* a model of evaluation that directly relates theory to practice.

In this regard, it is essential to understand that the name of a test or subtest does not necessarily reflect the function in question, nor does it necessarily reflect a neuroanatomically based brain-behavior relationship. This is obvious for certain subtest names, but this is not immediately apparent in relation to other subtests. For example, consider a subtest titled, “verbal fluency.” This is a behavioral function, but most neuropsychologists would agree that verbal fluency is not a unitary construct and that this “function” is multiply determined. In other words, the term “verbal fluency” must be operationally defined, and reference to the term as a holistic concept has no single agreed upon neuroanatomic locus. Performance on “verbal fluency” tasks can be influenced by the integrity of posterior brain regions, anterior brain areas, or both. It is more tempting to apply functional meaning to the names of certain other subtests.

For instance, a subtest of executive function might immediately be interpreted as referring to the integrity of the frontal lobes, when in fact, most measures of executive function are also multifactorial (Stuss, 2007; Stuss & Alexander, 2007). Measures of “auditory attention” or “visual attention” might imply that that this is the manner in which “attention” is organized within the brain. However, based upon neuroanatomical principles, extended brain stem and basal forebrain regions would appear to support most attentional functions, while the terms “auditory” and “visual” refer to the integrity of cortically based sensory-processing units that project information to these lower-level systems that support both auditory and visual attention (Dockstader et al., 2008). The underlying brain regions that support certain aspects of selective attention and associated “focus” or response inhibition have no sensory-perceptual capacities of their own, but instead, receive information from cortically based sensory-information processing units. In any case, neuropsychological tests frequently have very poor “face validity” (Anastasi, 1988).

In neuropsychological test interpretation, there can be a tendency to treat all sensory information processing systems as equivalent, when in fact, auditory, visual, tactile, and olfactory systems all possess unique properties and disturbances within these sensory processing systems will affect performance on tests of “attention,” even though the attentional system that supports these capacities might be intact. These subtle differences among processes are important because of treatment implications. For example, psychostimulant medications often enhance focused attention by addressing inhibitory control, making a child less vulnerable to responding to distracting influences. This class of medications affects dopaminergic activity within frontal-subcortical brain regions (Devito et al., 2008; Rosa-Neto et al., 2005). These medications do not appear to have an effect on the posterior brain regions that mediate the sensory processing of “auditory” or “visual” attention. In other words, these medications are effective because they enhance the performance of underlying brain regions that support attentional functions, regardless of specific sensory modality.

A significant disadvantage of fixed batteries is that they are impossible to update for the purpose of keeping pace with new developments emerging from the various disciplines of the neurosciences. Perhaps the easiest example to understand is the HRB described above. The tests that comprise this battery were standardized over 50 years ago. During this time, our knowledge of brain-behavior relationships has expanded exponentially. It is impossible to apply the HRB, as it stands alone, to the information, knowledge, and theories of various aspects of brain function that have emerged over the past half century or more. Said another way, it is impossible to apply contemporary neuroscience theory to practice by using the HRB. For example, the HRB has no subtests that directly assess the various subcomponents of attention, and it has no subtests that systematically assess the multiple component processes of learning and memory. Other cognitive domains can be discussed similarly. The HRB, like any other fixed battery, thus cannot easily be applied for a purpose other than for which it was originally intended. The only way to address these issues of lack of assessment coverage is to add other tests to the original battery. This expansion significantly changes the composition of the battery. In essence, this amounts to taking a “fixed” battery and modifying it with a “flexible” battery approach.

Test Selection: Flexible Batteries

A flexible battery approach allows an examiner to choose tests based upon the referral question, the characteristics of the child’s condition, complaints and symptoms, and even the child’s history. In this way, adaptations in test choice are possible to address the requirements of any particular evaluation situation. Many neuropsychologists work with a fairly predictable patient population and see a certain range of disorders and conditions on a reasonably regular basis. These examiners essentially develop their own “model,” which might be referred to as a repeatable fixed battery or personal core battery (Baron, 2004).

The flexibility allowed by this approach has numerous advantages. Tests can be economically chosen to answer referral questions while by-passing assessment of those functions assumed unlikely to be affected. However, this approach is not without risk. For example, in a behavioral and neuropsychological evaluation of Attention Deficit Hyperactivity Disorder and associated cognitive attentional functions, failing to evaluate the abilities that support reading and writing skill development or to obtain direct measures of academic achievement in these areas would leave a frequently co-morbid reading or written language disorder undiagnosed. As stated above, there is much truth to the saying, “you can only find what you look for” when conducting an evaluation. A flexible battery approach also runs the risk of choosing instruments that only address the child's reported symptoms and complaints. While this can lead to confirmatory bias in evaluation, this type of approach also assumes that symptoms are reported articulately and that all relevant symptoms are reported. In clinical practice, these are unwarranted assumptions (Reitan & Wolfson, 1997).

Deciding what tests to use in composing a flexible battery is also critically dependent upon the neuropsychologist's level of expertise. The competent neuropsychologist needs to choose tests based upon two important and related issues: First, the clinician needs to possess a thorough, *current* understanding of the functional neuroanatomy underlying whatever functions are to be measured. This is particularly important in pediatric assessment, given the context of a developing brain. In our view, it is "bad practice" to administer a test for the purpose of, "seeing how the child does on it." Instead, tests should be chosen as part of an overall plan to accomplish some aspect of the evaluation's goals. For example, reading disorder assessment requires a clinician to understand the individual component cognitive and language skills that support reading so that appropriate instruments can be chosen. This is a very different approach than simply administering a ready-made battery of reading subtests.

Similarly, to assess attention, the clinician needs to understand how attentional networks are organized within the brain in order to administer tests that evaluate the appropriate functions in sufficient detail. This approach is quite different than administering a continuous performance test to, "see if the child has ADHD," or to, "see how the child does on it." Further, when assessing learning and memory, test choice should be guided by an understanding of relative posterior and anterior brain functions to these processes, in contrast to picking a test battery because it is labeled as a "comprehensive assessment of memory." From this perspective, it is clear that a thorough knowledge of brain-behavior relationships is essential to the evaluation of every neurocognitive domain.

This brings us to our second point. A neuropsychologist requires expertise in evaluating tests and what they measure, rather than taking for granted what a test might purport to measure (Leffard et al., 2006). Surprisingly few tests are organized in a way that accurately reflects the organization of brain-behavior relationships as they are currently understood. For example, numerous commonly used memory batteries are composed in a way that fails to reflect how memory functions are organized within the brain, which can limit their ecological validity (Dubreuil et al., 2007; Makatura et al., 1999). Tests can also be scored to yield composite indices that actually "hide" or "bury" the brain-behavior relationships that may be of interest. Whenever scores are summarized into composite quotients, important data are lost, too often including the data that illuminate important brain-behavior relationships (Lezak, 2004). For instance, combining immediate recall scores from different modalities (auditory, visual, and verbal) can obscure important differences. Further, combining delayed recall scores from narrative recall and associative recall performances can lead to false positive findings; these subtests are not truly comparable as they measure different aspects of learning and memory.

Additionally, a test carrying a particular name does not necessarily measure only what the name implies. Take, for example, performance on a “Comprehension of Instructions,” or other Token-type task purporting to measure receptive language skills. A performance in the impaired range on this task does not necessarily mean that the child has a language comprehension problem, even though this interpretation is exactly what the title of the test would imply. In reality, this test requires not only language comprehension, but also attention and the serial-order processing capabilities inherent in working memory and associated cognitive control. In short, performance on most tests can be influenced by multiple factors. With this understanding, we can more carefully choose tests that will better clarify the specific areas or functions contributing to the problems undergoing assessment while avoiding the interpretive problems inherent in the concept of “face validity.”

Cognitive Domains: Organization and Analysis

We believe that competent neuropsychological evaluation is based upon very well organized, systematic, and pragmatic thinking. This starts with a solid theoretical understanding of the way behavior is organized within the brain, followed by knowing how to use or apply tests in relation to that anatomical organization. Next, the data that are obtained from the patient need to be systematically analyzed and interpreted, preferably by going through every case in the same way, every time. The neuropsychologist needs to know how to impose an organized structure upon test data in order to make clinical sense of that information. The goal of the remaining sections of this chapter is to emphasize developing a disciplined thinking approach, preparing a clinician to consider any practical clinical case.

To start with, we believe that an essential key for appropriate test selection concerns the organization of brain-behavior relationships into relevant domains. This level of organization assists with informed decisions in choosing a fixed battery, in constructing a flexible battery for any particular clinical case, or for modifying an existing test battery. These domain groupings reflect a systematic way to organize brain-behavior relationships. Each domain can be organized in the manner in which cognition and behavior are currently understood to be organized or represented within the brain. Since this chapter focuses upon cognition, our discussion will be restricted to the visual-perceptual-spatial, language, attention, learning and memory, and executive domains. The somatosensory and motor domains are also considered because of their potential relevance to cognition, particularly in children (Diamond, 2000b; Piek et al., 2008; Ullman & Pierpont, 2005; Viholainen et al., 2006; Webster et al., 2006). However, the methodology could easily be extended to include emotional, motivational, and social domains.

We will start with **the visual-perceptual-spatial domain**. For a neuropsychological evaluation, these data need to be organized and interpreted in the same way in which these processes are represented within the brain. So, why does this “domain” of function exist in the first place? In short, from an evolutionary perspective, the purpose of the individual is to survive through interaction with the environment. In order for any of us to accomplish this task, we need to know **what** objects are in the environment and **where** these objects are located. Sensory-perceptual processes are organized according to these principles. Object recognition functions (what) are subsumed by posterior ventral pathways, and object location functions (where) are subserved by dorsal pathways within the brain (Ungerleider & Haxby, 1994). These comprise the basic receptive processes of visual-perceptual-spatial functioning. Ideally, these functions should be assessed using object identification and location tasks within a recognition paradigm, but there are very few tasks that are organized in this manner. Most visuospatial tasks are contaminated by a requirement that the subject must in some way think about, manipulate, or perform some sort of cognitive operation with this information. Block construction and complex design copying tasks are prime examples of this type of multi-factorial contamination.

Constructional functions (such as measured by the aforementioned design drawing and block design tasks) are viewed as anterior in localization *while requiring the support* of posterior perceptual processes (Capruso et al., 1998). Therefore, good block design and design copying performances almost always imply intact ventral (object identification) and dorsal (object location) functions. However, poor block construction and/or design copying functions can relate to three possible factors: impairment in posterior perceptual functions, impairment in anterior (problem-solving) functions, or impairment in both. Therefore, assessment tasks that place heavy demands on posterior and anterior functions simultaneously tell us very little about the reason for the poor performances. In other words, poor block construction and/or poor design copying does not necessarily tell us anything about the integrity of visual-perceptual-spatial abilities per se. Poor performances may be telling us more about “problem solving” (using or applying visual-spatial information) than about visual “perceptual” processes. Perhaps this is one reason why many people obtain poor performances on block construction and design drawing tasks without demonstrating any “real world” deficits in visual-perceptual-spatial behavior. The general point of significance is that the results of tests that are multifactorial in composition obscure the interpretation of brain-behavior relationships.

In the anterior-posterior anatomical frame of reference, the central sulcus separates anterior from posterior cortices. All brain regions posterior to the central sulcus are considered posterior cortices, and regions anterior to this fissure are considered anterior. Therefore, the occipital, parietal, and temporal lobes are considered posterior; the frontal lobes and basal forebrain region are considered anterior brain systems. Tests and results are grouped into the appropriate domain and into the appropriate function within each domain. Tests and their interpretation should be differentiated according to their weight on posterior versus anterior processes.

This interpretive methodology greatly facilitates test data integration. This type of integration is important because it assists us in making anatomic sense of test data while requiring us to notice and evaluate any inconsistencies in results. However, in organizing evaluation data in this way, it is readily apparent that neuropsychological tests and instruments are not necessarily constructed along the lines of anatomic brain-behavior relationships. As described above, a test’s name often does not reflect a brain-related anatomic organization. Therefore, in order to group various tests within domains, a clinician's understanding of functional neuroanatomy, cognitive processes, and judgment in determining what tests actually measure are required. A number of tests are considered multi-factorial to the extent that they might be considered in more than one domain simultaneously. For example, a sentence repetition test might simultaneously be considered a measure of language function, a measure of immediate recall, and a measure of an element of attention.

The language domain is divided into receptive and expressive processes. The level of organization proposed here respects the brain-related representations of posterior/receptive and anterior/expressive functions. Tasks that emphasize speech sound discrimination, for example, are weighted with a posterior brain region perceptual component. A vocabulary task that requires identification or recognition of a word in contrast to self-generating word meaning is also weighted more towards receptive processes. A task such as the Token Test (comprehension of instructions paradigm) requires both posterior (perceptual) and anterior (serial-order processing) functions (Spreen & Benton, 1969). Tasks of semantic and letter word fluency can be used in combination to make differentiations concerning the relative integrity of anterior and posterior systems. For example, semantic fluency tasks require the retrieval of words by category, according to how words are presumably stored in "networks." This is largely dependent upon posterior brain regions. Retrieving words according to starting letter places an emphasis on prefrontal functions, since words are now being retrieved in a manner which is different from the way in which words are stored in semantic networks. Yet the tasks are similar because both require a retrieval process.

We also feel it is important to consider language as comprising both cortical and subcortical processes (Ullman, 2004; Ullman & Pierpont, 2005). It has been proposed that the automatic “rules” of language such as grammar are mediated by cortical-subcortical regions (that mediate procedural behaviors) and that the semantics of language such as vocabulary are primarily mediated by cortical processes (that largely mediate declarative memory functions). However, there are currently no commercially available cognitive, neuropsychological, or language tests that make any attempt to separate or recognize the organization of the declarative and procedural language systems. Any separation of function of this type thus currently results from qualitative test interpretation and behavioral observation. However, in clinical evaluation, a qualitative approach is justifiable.

The domain of attention is organized according to the model proposed by Mirsky (Duncan & Mirsky, 2004; Mirsky, 1996; Mirsky & Duncan, 2004). We use this model because of its simplicity and convenience in systematically evaluating attentional functions. We fully recognize that other models are justifiable (Cohen et al., 1998). A number of different models of attention can be employed, so long as attentional functions are measured in a systematic way. The “Mirsky model” divides attention into the dimensions of the initial registration or encoding of information, sustained attention, shifting attention, and the focus/execute element. Within the element of sustained attention, we have subdivided the dimensions of stimulus selection and response inhibition (Fuster, 1997) which are not components of Mirsky’s original proposal. This allows for a finer breakdown of function as related to the inhibitory component of attentional focus and control as mediated by the frontostriatal system. The focus-execute subdomain features test data that are considered to be related in some capacity to what is commonly referred to as "processing speed," insofar as "processing speed" refers to the amount of material processed per unit of time (Chiaravalloti et al., 2003; Reichenberg & Harvey, 2007).

However, when we define processing speed as the speed with which various cognitive operations can be performed, then "processing speed" is not "one thing" (Koziol & Budding, 2009; Saling & Philips, 2007). It is thus common to find variability in the scores placed within this domain. On neuropsychological tests, "speed" is often a by-product of executive or cognitive control. For example, the slower the speed, the more the cognitive "executive" control required to complete the task.

The executive domain is categorized according to four functions, specifically, working memory, inhibition, attentional shifting, and planning (Bennetto & Pennington, 2003; Pennington, 1997). We realize that the attention and executive domains therefore overlap. However, it always needs to be understood and remembered that the categories of different domains can and do share certain features. All systems that serve to categorize test results are arbitrary and superficial because many tests are multi-factorial and therefore fall in more than one domain. Thus, the divisions provided here should serve as a reminder that cognitive functions are integrated processes that are driven by brain networks, and that division into categories is always somewhat arbitrary and never completely “clean” or absolute. Keeping this in mind actually helps to avoid fragmented thinking about patients during the process of test interpretation.

It can readily be argued that inhibition and working memory are the abilities that developmentally support all executive functions (Denckla, 1994; Denckla, 1996). Without an ability to “not respond” to the immediate, we cannot develop the capacity to “think” about anything other than that which is right before us. Without working memory, we cannot develop the capacity for higher-order, self-directed control over behavior. Working memory *is* cognitive control, and cognitive control *is* working memory. For example, the ability to change attentional focus and shift from thinking about one concept to another, as well as the ability to plan ahead hinge upon background functions of working memory and inhibitory control (Asato et al., 2006). Further, inhibition and working memory are the two functions that support the “serial order processing” of cognitive and motor control (Aron et al., 2007; Beiser & Houk, 1998; Frank et al., 2001; Herd et al., 2006; Rubia et al., 2006; Wilkinson & Jahanshahi, 2007) . For example, parallels can be drawn between motor plans, cognitive plans or working memory, and higher-order cognitive control (Badcock et al., 2005; Dehaene & Changeux, 2000). Consider the act of moving furniture around a room in a predetermined way versus thinking about or making a “plan” to rearrange the furniture (Vandervert et al., 2007). Both of these tasks, one motor and the other cognitive, require information maintenance and the serial-order processing of that information. Once the brain codes information into neural impulses, motor and cognitive information are treated equivalently (Ito, 1993). The architecture of frontal-basal ganglia circuitry or “loops,” which allow both inhibition and working memory updating, form the underpinnings of serial-order processing. It is this anatomic organization that generates the viewpoint that higher-order cognitive executive control is the evolutionary extension of the motor control system (Ardila, 2008; Frank & Claus, 2006; Hazy et al., 2007b; Stout et al., 2008). This, then, is at the heart of executive function.

We follow Squire's model in relation to assessing **the declarative learning and memory domain** (Squire & Shimamura, 1996). Learning is defined as the acquisition of information and memory is defined as the persistence of that learning over time. Therefore, memory is very narrowly defined as the retention of newly presented information. This is considered a posterior function, initially dependent upon the integrity of the hippocampal system within the medial temporal lobes, which is best measured by recognition paradigms. The retrieval functions are considered to be mediated by the anterior frontostriatal system (Squire et al., 2004; Yener & Zaffos, 1999). Therefore, in organizing learning and memory data, distinctions need to be made between immediate recall, the rate of information acquisition through multiple trials with the same material, voluntary information access during delayed free recall trials, and recognition memory evaluating retention or storage of new information. Conclusions about the integrity of the mechanisms that support learning and memory are derived from test score comparisons, rather than merely assigning meaning to any one component score or global index.

The final domain consists of **sensory and motor functioning**. We believe it is preferable and advisable to interpret sensory and motor systems separately. We adhere to this distinction for two reasons. First, this methodology respects functional anatomic organization. Sensory-perceptual processes are mediated by posterior sensory brain regions, and motor functions are subserved by anterior brain regions. It is true that every motor action requires sensory input. However, sensory perception can be assessed without requiring significant motor response. This allows for discriminations as to whether deficits lie on the sensory or on the motor side of the sensory-motor equation. This assists in neuroanatomic localization. Second, this division relates to adaptive function. Sensory-perceptual processes are passive-receptive functions that in isolation do not require executive, higher-order control. They require recognition functions and they assist in object identification and object location. On the other hand, motor control and executive function are intimately related.

Cognitive control can be understood as an "extension" of the same frontal and basal ganglia interactions that control movement (Frank et al., 2001; Hazy et al., 2007). This translates the principles of movement to thought. The process of child development can be conceptualized as the acquisition of increasing control over the motor system (Kinsbourne, 1993; Slattery et al., 2001). Controlled motor function is, by definition, executive control. Motor development clearly corresponds with the development of higher-order executive control processes, and is thus a critical area to assess in children (Diamond, 2000; Foerde et al., 2008; Olivier et al., 2007; Piek et al., 2008; von Hofsten, 2007). Therefore, we believe that combining sensory-motor functioning as a unitary concept usually results in a critical loss of interpretable data that otherwise can guide diagnostic decision-making and treatment planning. This distinction is of particular significance in pediatric cases, in which dissociations between sensory and motor function are common and are of differential diagnostic importance. On this basis, we treat sensory/somatosensory and motor data separately.

Test Interpretation Methodology: Levels of Inference

After having gathered and organized data according to a model that reflects the organization of brain-behavior relationships, the next step is to follow a systematic interpretation strategy within each domain. The interpretative methodology that we propose was initially developed by Reitan (Reitan, 1974; Reitan, 1975). However, the methodology can be applied to any cognitive data, without relying on any of the specific tests of the Halsted-Reitan assessment approach. We believe that it is important to apply the same systematic interpretative methodology to every case, every time, in order to ensure a comprehensive understanding of the data. Non-systematic approaches can lead to superficial interpretations and false negative and false positive findings.

The three most important inferential methods in this system are directly related to cognition. These methods of interpretation comprise evaluating a person's *level of performance* in relation to normative data, *comparison of performances* across cognitive tests of relevant dimensions (also referred to as pattern analysis), and assessment of *pathognomonic signs*. A fourth level of inferential analysis is *body-side comparison*, though this fourth methodology might not always reflect cognitive status, since in certain cases, sensory and motor functioning can be affected by pathology peripheral to brain functioning. Please see Lezak (1994, 2004) or Baron (2004) for further description of these levels of analysis. In addition, certain sensory and motor information that is usually considered in body-side comparisons can be used in other comparisons, in other domains, and sometimes even in a pathognomonic manner. For instance, impaired competing programs go-no go motor tasks performance is often interpreted as specific signs of deficit within the executive domain of "inhibition." However, unfortunately, while every case for clinical evaluation consists of cognitive data, not every case includes the type of sensory and motor data necessary for body-side interpretive comparisons. This stems from the persistent but misleading notion that sensory and motor functions are "non-cognitive" in terms of interpretative implications.

Methods of Test Interpretation

The first and most basic inferential method is **the level of performance**. In this method, a test score is compared to an objective normative standard. A "good" level of performance typically implies healthy brain-related ability for the function in question. However, this is not always the case, since an interpretation at this level can be modified through test pattern analysis when comparing a particular performance to other test data. For example, against the background of test scores within a superior range, an "average" test performance might actually be indicative of a cognitive deficit. This type of interpretation has also been referred to as an individual comparison standard (Lezak, et al., 2004). A "poor" level of performance in isolation never provides any information concerning the reason for that poor performance (Anastasi & Urbina, 1997). Therefore, a poor performance on any single test might be due to of any one of multiple factors. Simply comparing a performance on any single test to a group normative standard does not necessarily speak towards the integrity of a brain function, even if test score standards were derived from populations with documented brain damage.

As an example, consider an analogy from medicine, the hemocult test used by a primary care physician or internist. Does a positive finding diagnose colon cancer? Does a positive result point to internal bleeding? Of course not. The hemocult test "tags" for iron. Therefore, the test is sensitive to any factor that produces iron content within the sample. Even a healthy diet with spinach will generate iron content and produce a positive result. Therefore, a "positive" result might have either the most pathological or the most benign interpretation. The same principle holds for neuropsychological testing. Neuropsychological tests "tag" cognitive function in a way that is analogous to the hemocult test "tagging" iron. ***Neuropsychological tests are sensitive to any condition or factor that can influence cognition***.

Test score comparisons are often more useful than simple level of performance criteria, and this represents the second level of inference in analyzing test data. Comparing test scores often generates synergistic interpretive information because doing so provides data that would not be available through simply interpreting scores in isolation. For example, scores on semantic/category fluency tasks and scores on letter/phonemic fluency tasks might not say very much when interpreted individually, but comparing category and letter fluency scores with each other can often generate information about the integrity of posterior versus anterior brain-related language and executive processes. Many diagnostically powerful neuropsychological inferences can be generated by this synergistic methodology. We believe that organizing test data according to the above-detailed concept of functional domains assists the examiner in structuring *relevant test score comparisons*. We can see how this might be the case in evaluating the learning and memory domain. A low or mid-range score on a long delay free recall trial of a word list learning test might not mean very much by itself. However, when compared to an error-free performance in a recognition condition, this performance might generate the inference that information retention is completely intact but that problems exist in voluntary retrieval or access to that information. It could be further inferred that practical management of this deficit can be enhanced through the use of “familiarity” paradigms or “reminders” within the environment, and that the likely anatomic substrate for this test pattern concerns the anterior frontostriatal system. Therefore, a diagnostic wealth of information emerges from the comparison of performances, and this is information that could not be known by simply interpreting scores individually according to basic level of performance criteria.

Normal and Dichotomous Distributions

When neuropsychological test metrics are described in terms of standard scores, it is tempting to conclude that the measured function follows a normal probability distribution. However, a number of abilities and skills do not follow a normal distribution of scores within the general population, even though the test publisher may have assigned ranges of performance with standard scores (Benton et al., 1994). There is also a difference in approach between trying to measure a full range of behavioral characteristics and trying to identify a problem or disease characteristic. While performance on many cognitive tests is dependent upon multiple functions, we can say in general that the more multi-factorial variables are contained within the test, the more likely it is that performance on that test will be normally distributed within the general population (Lezak, 2004). Put another way, as the number of abilities necessary for successful performance on the test increases, the more likely it is that the test norm approximates a *"bell shaped curve."* However, a focus on the identification of pathology or of a disease process typically includes detecting behavioral "signs" that follow a *dichotomous distribution* (Reitan & Wolfson, 2008).

These latter types of test data are simply not normally distributed and need to be interpreted within the context of **pathognomonic or specific signs**. This means that almost each and every time the performance is observed, it points to a lack of integrity in brain-related functions. For example, disorientation in an adolescent patient, dysphonetic spelling errors in school-aged children, errors of commission on certain specific continuous performance tests and go-no go tasks, and rule violations on tower tests comprise a few examples of behavior that are considered pathological simply on the basis of their occurrence. Errors such as perseverative responses and failures to maintain set on the Wisconsin Card Sorting Test are also not normally distributed. The frequency of these types of errors is different for different ages of child populations, but these behaviors do not follow a bell-shaped curve at any age. These behaviors almost always have pathognomonic interpretive significance, but cannot be reliably interpreted by using a pathognomonic approach in isolation.

In **body-side comparisons**, the functioning of the dominant and non-dominant hands is compared in sensory and motor domains. Comparing the functioning of one body side with another can implicate the contralateral cerebral hemisphere when a sensory or motor deficit is observed. In addition, deficits in sensory-perceptual functioning (on tasks such as finger localization) typically implicate involvement of posterior brain regions while deficits in motor functioning typically imply involvement of anterior brain regions. We tend to view sensory body side comparison data as significant mostly when these results correspond with cognitive pathology identified by other aspects of test data. In other words, these data are viewed as supportive of interpretations generated from direct cognitive test results. This is because data concerning sensory and motor functioning can also be affected by factors that are peripheral to cognitive processes (such as fracture or other damage to a limb).

We favor a motor examination that systematically evaluates and hierarchically “layers” motor functions. The guiding principle concerns the fact that higher-level motor functions must be expressed through lower level systems. It is anatomically impossible to execute an “intact” higher-level motor skill through a deficient lower-level motor system. For example, a task such as finger tapping is relatively straightforward and “taps” the “lower-level” motor systems of “posterior” regions of frontal motor cortices, such as the precentral gyrus, commonly referred to as the primary motor cortex or the vernacular “motor strip.” Tasks such as “finger sequencing,” or touching each finger, in order, over repetitive trials recruits frontal regions anterior to primary motor cortex, in the premotor and supplementary motor areas. More complex tasks, such as learning new motor movements involving multiple limb movement combinations, or tasks that involve the executive coordination of bi-lateral limb movements, involve even more anterior frontal cortices, and can include dorsolateral prefrontal cortices (Banich, 2004; Luria, 1973; Luria, 1980).

Therefore, the motor system can be evaluated very *systematically*. Based upon the premise that motor control is the “precursor” of higher-order control, this methodology has implications for executive function, which ***is*** frequently the focus of neuropsychological evaluation (Diamond, 2000; Kinsbourne, 1998; Piek, 2008; Viholainen, 2006). However, this methodology is not often employed in traditional American neuropsychology. The NEPSY series does make an attempt to evaluate motor programming in this way, but the item composition of the motor programming subtest is not systematic (Goldberg et al., 2000; Luria, 1973). For some reason, this subtest does not extend to include the 12 to 16 year age range on the NEPSY. However, since a strong argument can be made that motor programming ability approximates adult performance within that age range (Welsh et al., 1991), it might also be proposed that 12 to 16 year old subjects would not demonstrate significant differences in their performances. It would seem unlikely that performances on motor programming measures would follow a normal distribution since the items are theoretically low on a “mulitfactorial dimension.” In addition, motor ability in normal controls develops through the ages of 12-16, with little change thereafter (Welsh et al., 1991).

Anatomical Models for Test Interpretation

Traditional neuropsychology is founded upon a cortico-centric model of cognition. In this view, the cortex is considered the seat of cognitive functioning, while the basal ganglia and cerebellum are considered mainly as co-processors of movement. In a sense, the cortex is divided into quadrants following a lateral and horizontal gradient. Grossly speaking, the left hemisphere is believed to control language function and the right hemisphere is believed to mediate non-verbal function. In this way, the lateral organization of the brain is considered to follow a verbal versus non-verbal dichotomy. The posterior lobes of the brain (occipital, parietal, and temporal lobes) serve sensory-perceptual functions and the anterior regions of the brain (the frontal lobes) mediate motor or “action” functions. This view represents a succinct “package” that can generate a false sense of security in organizing and interpreting neuropsychological test data. In our opinion, the cortico-centric viewpoint is overly simplistic and can even be misleading because it pays too little attention to the significance of the brain’s vertical organization.

There are two vertically organized re-entrant brain systems that interface the cortex and descending systems. These comprise the cortico-basal ganglia system and the cerebro-cerebellar system (Houk et al., 2007; Seger, 2009). They are termed re-entrant systems because their circuitries form a “loop”- the circuit re-enters a region near its point of origin. The circuits originate in the cerebral cortex. After passing through the various subcortical structures within each respective system, the circuit re-enters the cortex and terminates very near the same region in which the circuit originated. Therefore, a general feature of these circuits comprises a **cortical-subcortical-cortical** loop of interaction. Within the nervous system, loops of interaction of this type are considered to have a modulatory function. In these two systems, the cortical inputs are always excitatory. Outputs from these subcortical regions are largely inhibitory. This means that these subcortical circuits are regulating or modulating—and thus changing—the nature of input received from various cortical domains. Therefore, ***these subcortical regions play an important role in deciding what information is or is not returned to the cerebral cortex*** (Andreasen & Pierson, 2008; Schmahmann & Pandya, 2008). This "looped" architecture represents an organizational system central to brain-behavior relationships, and therefore, in a broader context, these circuitries are central to neuropsychology.

The process of adaptation is not "all cortex." There appear to be two systems around which behavior and cognition are broadly organized. One of these systems mediates stimulus-based responding. This system is composed of innate behaviors and those behaviors that run on the basis of acquired associations (Toates, 2004; Toates, 2006). This system allows for automatic responding in familiar or predictable situations. These behaviors are adaptive, since they allow for exploitation of the predictable features of the environment while conserving cognitive and higher-order resources. This is because these behaviors do not require higher-order thinking or control. At the same time, this system acts in the "best interest" of the organism as a whole (Miller, 2008). Therefore, this system can be considered part of the brain's "emotional/motivational" executive system (Ardila, 2008). Although the behavior mediated by this system is stored in cortex, the basal ganglia and cerebellum are necessary to "bind" and "refine" the appropriate behavioral sequences (Graybiel, 2005; Graybiel, 2008; Houk & Mugnaini, 2003).

The second system is based upon higher-order control. This system allows for novel problem-solving and provides for flexibility in interacting with changing and unpredictable environments (Toates, 2004; Toates, 2006). This system allows for developing responses for which there are no predetermined or known solutions to problems. In this regard, behavior and cognition do not appear to be organized around a verbal versus non-verbal dichotomy. Instead, the system of behavioral control appears to be organized along a novelty-routinization principle (Podell et al., 2001). The ultimate goal of this system is to make familiar that which is initially novel or unfamiliar, because doing so provides a decisive advantage for adaptation. We believe this is a critically important point, since we view a neuropsychological evaluation as a "special instance" of adaptation within a novelty-familiarity principle. Most situations require alternating episodes between automatic behaviors and higher-order control. This should represent a fundamental underlying principle for neuropsychological test interpretation as well.

The Case for Consistent Assessment Standards

We feel strongly that our field would benefit from consistent standards guiding assessment practice. Rather than trying to standardize "fixed" versus "flexible" battery approaches, or psychometric versus process approaches, we would be better served by establishing neuroanatomically and domain based standards that all neuropsychologists could follow to ensure greater consistency and inter-rater agreement with regards to findings.

For example, every cognitive domain that is evaluated needs to fulfill certain criteria to do justice to assessing the function. A learning and memory evaluation, at the bare minimum, needs to include an assessment of immediate recall, measurement of learning across multiple trials, delayed voluntary recall trials, and an assessment of storage in a recognition condition. All of these functions need to be specifically described in an interpretive report. It remains the examiner's prerogative to choose a test or combination of tests to evaluate those functions. The guidelines would specifically indicate what areas need to be measured and described. Similar protocols would be established for other cognitive domains such as attention, executive functions, language and visual-perceptual-spatial functions, and sensory and motor areas. We have outlined our views regarding areas to be covered above.

Other independent professions have standards of practice. For example, internists have guidelines to follow for GI work-ups, pediatricians have a protocol for assessing ADHD, the American Psychiatric Association has guidelines for the behavioral diagnosis and treatment of psychiatric conditions. Neuropsychology needs to follow suit to promote uniformity of practice in relation to neuropsychological descriptive diagnosis.

There are obvious anticipated objections to this position. One of these is the viewpoint that "there is more than one way to skin the cat." This is simply not true in neuropsychology, just as it is not true in medicine. Physicians have a limited number of recognized options available for "good practice" in diagnosing and treating various conditions. For example, in neuropsychology, if an examiner hasn't systematically measured attentional functions according to known theoretical neuroanatomic models, or if an examiner hasn't compared voluntary delayed and recognition recall trials, then the respective domains of attention and memory have not been adequately assessed. There may be many ways to skin the cat with respect to *test choices*, but there are limited ways to approach the functions in terms of the way cognition/behavior is organized within the brain. The methods chosen need to reflect that organization.

Another potential objection concerns the fact that there are ongoing changes in the development of our understanding of cognitive functions. Once again, this is true for all professions based upon a scientific knowledge base. All professions have to deal with ongoing changes. For example, 25 years ago, a neurologist would have relied upon different imaging techniques in diagnosing brain tumors than the methodologies used today. Any guidelines and standards of clinical practice that are employed can only be expected to represent interim solutions that are subject to modification as our knowledge base and technology develop. It can even be argued that greater uniformity in clinical approaches contributes to the advancement of the profession's knowledge base.

Sample Case Interpretation

These principles need to be applied to neuropsychological test interpretation, which is illustrated through the following case. (For a complete review of this viewpoint, see Koziol & Budding, 2009.) While most real-life situations require alternating episodes of automatic responding with higher control, neuropsychological testing and data interpretation provide a sample of this process. The following case interpretation, first presented in “Subcortical Structures and Cognition” (2009), illustrates an approach similar to the one described by Baron (2004), in which theory and practice are integrated. However, our model departs from a strictly cortico-centric model, differing on the basis of directly relating cortical processing to basal ganglia and cerebellar functioning. This illustrates our view that test interpretation should focus on brain-behavior relationships, with three potential sources of variability that influence neuropsychological test interpretation, namely, the cortex, basal ganglia, and cerebellum (Alvarez & Emory, 2006; Hirata et al., 2006). The current lack of discriminatory power in test data suggests that neuropsychological test results should be described in cognitive and behavioral terms, instead of in anatomic terms.

This is a 10 year old right-handed male. He has been diagnosed with Asperger’s disorder, but he demonstrates comorbid pathology that could be diagnosed under the rubric of Tourette’s syndrome. He demonstrates many symptoms of AD(H)D and OCD. As reviewed by Yaryura-Tobias, and others many children with developmental disorders simultaneously fulfill diagnostic criteria for 1 to 5 DSM diagnoses (Yaryura-Tobias et al., 2003). This was a very preterm baby who was born at 26 weeks gestation. Cerebellar and cerebral structural abnormalities often co-occur as a result of very pre-term birth (Limperopoulos et al., 2005b). Cerebellar growth and development are rapid during late gestation, but this growth is impeded by premature birth (Limperopoulos et al., 2005a). Very pre-term birth is associated with three possible patterns of abnormalities in cerebellar development. First, there can be volume reduction of the cerebellar hemispheres and a smaller vermis. Second, there can be volumetric cerebellar hemispheric reduction with an enlarged fourth ventricle and deformed vermis. Third, there can be normal cerebellar shape but with extensive reduction in its dimensions (Messerschmidt et al., 2005). These types of cerebellar abnormalities have been associated with a variety of cognitive, emotional, and non-motor difficulties (Allin et al., 2001; Allin et al., 2005; Herbert et al., 2004; Kessenich, 2003; Parker et al., 2008). There is also an association with white matter/mylenation abnormalities and with ischemic hemorrhagic events (Back et al., 2007).

White matter abnormalities and tissue changes from hemorrhagic events increase the likelihood of lesions within prefrontal-subcortical circuitries, including the dorsolateral, orbitofrontal, and medial regions. Structural abnormalities within these cortical-subcortical brain regions could anticipate problems in motivation, affective regulation and social cognition and behavior, as well as attention/executive deficits. Therefore, he is at risk for developing the myriad problems often seen in the full-blown characteristic presentation of Attention Deficit Disorder.

Abnormalities in cerebellar development as a result of very pre-term birth have been associated with the types of deficits seen in the cerebellar cognitive affective syndrome (Schmahmann, 2004). These problems also include deficits in attention, executive function, language skills, visuospatial information processing, learning disabilities such as reading disorder, as well as in difficulties with affective regulation and personality functioning (Schmahmann, 2004; Kessenich, 2003).

The point is that knowledge of developmental brain-behavior relationships should provide a background for guiding thinking towards establishing a framework within which to develop hypotheses about the patient's current presentation. This type of organizational framework is often the key to understanding the patient's presenting problems, rather than trying to simply establish a differential diagnosis based upon the observations of DSM-type criteria. In these ways, knowledge of the patient's history can be critical to conceptualizing the case, its brain-related descriptive diagnosis, its treatment, and prognosis. The patient in fact experienced "brain bleeds" in the perinatal period. Therefore, this case history presents a fertile groundwork for establishing hypotheses about developing a variety of cognitive-emotional-social adaptive problems.

A variety of behavioral observations about this patient are informative. He exhibits oro-facial dyskinesias, involuntary choreo-athetoid types of movements involving the mouth and nose, sometimes referred to by parents as facial twitches. He sometimes feels compelled to "spin" during the process of walking. At school, he sometimes has to "spin" and kick the wall. Therefore, he also demonstrates complex motor tics. These are significant findings in terms of guiding the clinician's thinking. These types of behaviors, which can be considered to reflect diminished control over intention, are considered mediated by prefrontal-basal ganglia circuitry (Frey & Albin, 2006). As prefrontal-subcortical circuitries descend towards the basal forebrain, there is a geographic spatial constriction of these separate circuits, so that a "lesion" primarily impacting one individual circuit can easily impact upon another. As these circuits descend within the brain, they begin to converge and become more closely packed. It becomes easy to imagine motor, cognitive, and emotional-social behavioral manifestations as a result of abnormal structure or chemistry of the basal ganglia, as the circuits begin to share the same geographic territory (Denckla & Reiss, 1997).

The patient also has a history of severe hypersensitivities. These sensitivities were evident with respect to sound, resulting in his attending to sounds that others would barely notice. Similarly, he was hypersensitive to clothing, such as the tags and labels on underwear. These types of behaviors imply two subcortical abnormalities. First, this suggests an abnormality in lower level basal ganglia-subcortical circuitries that gate orienting responses (McHaffie et al., 2005). He does not easily inhibit or "habituate" to these stimuli. These lower level stimuli compete for limited attentional resources and are disinhibited as a manifestation of abnormal basal ganglia selection mechanisms. Second, the intensity with which these stimuli are experienced reflects a disturbance in his modulation of the "force" of stimuli, so that not only is he distracted by these things, but he also experiences them as intense or excessive (Schmahmann, 2007). This implies abnormal cerebellar amplification. There are disturbances in both the selection and refinement of sensory stimuli or sensations.

Other behaviors are just as informative. He is unable to tie his shoes. It takes him a very long time to get dressed and to perform personal hygiene activities. He needs constant reminders to do simple things such as hang-up his coat. He typically forgets to take his lunch with him. He forgets to take his homework to school. He is easily distracted in the performance of all of these routines, which implies difficulties in his acquiring and implementing basic routines. His engaging in these behaviors is slow and inefficient because they are likely under conscious, higher-order control, without adequate (or possibly any) assistance from subcortical participation. In this way, his behaviors suggest a disturbance of procedural learning systems. He cannot perform behaviors automatically or quickly, but instead, under conscious mediation (Kubler et al., 2006; Saling & Phillips, 2007). This necessarily requires effort and higher levels of concentration, and is easily disrupted by distracting influences. His slowness likely emerges because the basal ganglia and cerebellum are important for learning to perform tasks automatically and thus quickly. He is left to perform tasks in a deliberate fashion when they should ordinarily be executed by habit (Knowlton, 2002).

The patient was entirely cooperative during the assessment. However, many aspects of his behavior were noteworthy. His speech pragmatics were impaired, and he frequently interrupted the examiner while being given instructions. His speech was often off-topic and tangential. He began tasks impulsively, often before instructions were completed. His prosody of speech was atypical and excessive in terms of emotional force, vocal volume and pitch. He made unusual statements, adding extreme aesthetic attachment to mundane aspects of the office, such as exclaiming, “what a beautiful doorknob.” His speech was highly tangential. He was not motorically hyperactive, but he would immediately touch whatever was placed on the desk in front of him. He would start to turn pages on the easel test administration book in front of him and he was insistent that he be allowed to pursue this ambition. When given a break for a snack and taken to the reception area, he insisted that the door remain open so that he could keep the examiner in view. When the examiner used the rest room, he insisted on waiting outside the door. When he did eat a snack, he would stuff his mouth very full, to excess.

These are important observations because they can be interpreted as demonstrating disturbances both in intention programs and in adjusting the amplitude of behavior. For example, his behaviors reveal difficulties in knowing when to start a behavior, when not to start a behavior, when to persist with a behavior, and when to stop a behavior. These intention programs are presumably under the mediation of basal ganglia circuitries (Koziol &Budding, 2009). Even his difficulties in separating from the examiner can be understood within the framework of a perseveration. It is important to realize that motor behaviors have cognitive and affective analogues, and this is very evident in his behavioral and affective predispositions. His excessive prosody and even his stuffing his mouth with food have the quality of disturbed behavioral amplification, with his “over shooting” the target or goal of the behavior. In these ways, observations of statements, emotional expression, and actual behavior can all be translated into motor equivalents, and can be formulated within the framework of subcortical contributions to the observable presentation. Again, in this regard, cognitive and affective functioning can be viewed as organized in parallel with the motor control system. Similarly, the interpretations of these observations can be weaved together with history and presenting symptoms, all of which implicate the same regional brain areas of involvement, specifically, prefrontal-basal ganglia and cerebro-cerebellar systems.

He obtained the following scores on a battery of neuropsychological tests:

INTELLECTUAL FUNCTIONG

Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV)

Verbal Comprehension		**Perceptual Reasoning**	
Similarities	10	Block Design	13
Vocabulary	6	Pic Concepts	7
Comprehen	1	Mat. Reason	11
(Information)	6	(Pic Complet.)	9

Working Memory		**Processing Speed**	
Digit Span	14	Coding	4
# fwd 8		Sym.Srch	1
# bkwd 5			
LN Sequen.	1		
(Arithmetic)	4		

Verbal Comprehension	75 (5%ile)
Perceptual Reasoning	102 (55%ile)
Working Memory	86 (18%ile)
Processing Speed	59 (<1%ile)
Full Scale IQ	76 (5%ile)

ATTENTION/CONCENTRATION

REGISTRATION/ENCODING

***WISC Digit Span forwards**	longest = 8	ss14
***WISC PI Spatial Span forwards**	longest = 3	ss 4
***CVLT Trial 1**	words 6	0 SD
***CVLT List B**	words 7	.5 SD
***NEPSY Narrative Memory**		ss 11

***NEPSY Sentences** ss 11
***NEPSY Faces Short Delay** 16/16 ss 15
***NEPSY Mem. For Names** 1 6/8
***CMS Story Recall, Immediate** ss 3

FOCUS-EXECUTE

***WISC Coding** ss 4
***WISC Symbol Search** ss 1
***NEPSY Visual Attention** ss11
***NEPSY Auditory Attn/Rsps Set** ss11
***Trails A** 27.9 seconds SS 106

SHIFTING

***WCST PSV RSP** SS99
***WCST PSV Errors** SS98
***D-KEFS Color-Word Switching** ss 11

SUSTAINING

***Gordon Diagnostic System**

GDS VIGILANCE SUBTEST

Summary Data		Selection Position		Tracking Data
Total Correct	40	1	0	19X
Block 1	15	2	1	XX9
Omissions	00	3	0	XX1
Commissions	03	4	2	X1X
Block 2	13	5	1	X9X
Omissions	02	6	0	XXX
Commissions	00	7	41	Block 1 Latency
Block 3	12	8	44	Block 2 Latency
Omissions	03	9	44	Block 3 Latency
Commissions	01	0	43	

Overall	Number	Classification	Percentile
Total Correct	40		14
Commissions	4		22
Omissions	05	-	

GDS DISTRACTIBILITY SUBTEST

Summary Data		Selection Position		Tracking Data
Total Correct	19	1	3	19X
Block 1	05	2	1	XX9
Omissions	10	3	1	XX1
Commissions	06	4	1	X1X
Block 2	07	5	0	X9X
Omissions	08	6	1	XXX
Commissions	00	7	47	Block 1 Latency
Block 3	07	8	44	Block 2 Latency
Omissions	08	9	42	Block 3 Latency
Commissions	01	0	44	

Overall	Number	Classification	Percentile

Total Correct	**19**		**7**
Commissions	**07**		**23**
Omissions	**26**		

*__WCST__ set losses 4 <1 percentile

EXECUTIVE FUNCTIONS

PLANNING

*__Tower of London__
Unscorable
***WISC III Mazes** ss 11

INHIBITION

***Gordon Delay**
Total Correct 36
Total Rspns 39
Total ER .92

***Gordon Vigilance/Distractibility Commissions** 4/7
***NEPSY Knock and Tap** 3-10 percentile
***NEPSY Statue** 3-10 percentile
***NEPSY Auditory Attn Commissions** 11-25 percentile
***NEPSY Rspns Set Commissions** <2 percentile
***DKEFS Color Word Interference**
Inhibition time 50 percentile
Inhibition errors 5 percentile

SHIFTING

***WCST**

128 Trials	90 Correct	
38 total errors	SS 96	39%
18 PSV RSP	SS 99	49%
17 PSV Err	SS 98	49%
21 Nonpsv	SS 92	45%
62% Concept.	SS 98	49%
4 cat. Completed	6-10%	
32 trials to first	2-5%	
4 set failure	<1%	

IDEA GENERATION

***NEPSY Verbal Fluency** ss 12
Semantic >75 percentile
Phonemic 11-25th percentile
***NEPSY Design Fluency** ss 1

WORKING MEMORY

***WISC Digit Span** backward	longest: 5		ss 16
***WISC PI Spatial Span** backward	longest: 4		ss 7
***WISC Arithmetic**			ss 4
***WISC LN Sequence**			ss 1
***Auditory Consonant Trigrams**			
0" delay	15 correct		
3" delay	7 correct	SS 81	
9"delay	4 correct	SS 84	
18"delay	7 correct	SS 107	

LEARNING AND MEMORY

***CVLT**

List A Trial 1	6	0 SD
Trial 2	8	
Trial 3	5	
Trial 4	6	
Trial 5	13	1 SD
List B	7	.5 SD
Total		T 40
Short Delay Free Recall	11	.5
Short Delay Cued Recall	11	.5 SD
Long Delay Free Recall	5	-2 SD
Long Delay Cued Recall	11	.5 SD
Recognition	13/15	0 SD

***CMS**

Immediate	1/15	ss3
Delayed	1/15	ss3
Recognition	22	ss1

***NEPSY Memory for Faces**	Immediate 16/16	ss15
	Delay 16/16	ss14
***NEPSY Memory for Names**		
Learning 22/24		ss14
Delayed 8/8		ss12
***NEPSY Narrative Memory**		ss11

LANGUAGE

COMPREHENSION

***NEPSY Comprehension of Instructions** ss10

REPETITION

***NEPSY Sentences** ss11
***NEPSY Repetition of Nonsense Words** ss15

PHONOLOGICAL AWARENESSS

***NEPSY Phonological Processing**	ss 11

NAMING

***NEPSY Speeded Naming**	ss8
***D-KEFS Color Naming**	ss9
Word Reading	ss9
***NEPSY Verbal Fluency**	ss 12
Semantic	>75 percentile
Phonemic	11-25th percentile
***DKEFS Word Naming**	ss8
***DKEFS Color Naming**	ss5

VISUAL PERCEPTUAL/ SPATIAL

***WISC Block Design**	ss13
***WISC Matrix Reasoning**	ss11
***NEPSY Design Copy**	ss10
***NEPSY Arrows**	ss1
***NEPSY Block Construction**	ss11

SENSORIMOTOR

***NEPSY Finger Discrimination**	3 errors dom	3-10 percentile
	4 errors non-dom	3-10 percentile
***NEPSY Oromotor Control**		26-75 percentile
***NEPSY Fingertip Tapping**		ss9
***NEPSY Imitating Hand Positions**		ss6
Preferred 9/12, Nonpreferred 10/12		
***NEPSY Visuomotor Precision**		ss4
***NEPSY Manual Motor Sequences**		26-75 percentile
***Grooved Pegboard**		
Right 113 seconds, 2 drops		SS 88
Left 107 seconds, 1 drop		SS 90

ACHIEVEMENT

***Gray Oral Reading Tests-Third Edition (Form A)**

	ss
Rate	7
Accuracy	9
Comprehension	5

***Wide Range Achievement Test- Third Edition**

Spelling	Grade Equiv. HS	SS93
Reading	Grade Equiv. 5	96
Arithmetic	Grade Equiv. 4	76

This child obtained a WISC-IV Full Scale IQ of 76. Although this score technically falls within a “borderline” psychometric range, this finding is impossible to interpret with any sense of clinical confidence because the individual index scores which comprise the FSIQ value are characterized by such significant variability. He obtained a Verbal Comprehension Index of 75, a Perceptual Reasoning Index of 102, a Working Memory Index of 86, and a Processing Speed Index of 59. Therefore, to the extent that the PRI serves as a very general problem-solving index, he performed like anyone else within that overarching domain, whatever it is that those multifactorial subtests measure. Verbal weaknesses are readily evident. The Similarities subtest items are highly structured and he performed as well as anyone else his age along that verbal concept formation dimension. However, difficulties were evident on those subtests that required self-organization of language processes.

He encountered difficulty generating definitions to stimulus words and he found it even more difficult to generate solutions to questions requiring him to apply age-appropriate common sense thinking. Performances on so-called working memory subtests were inconsistent, with solid scores in repeating digits forwards and backwards and great difficulties on Letter-number sequencing. His very low level of performance actually implies he had difficulty understanding the idea behind the subtest. With respect to the so-called Processing Speed Index, he obviously performed very slowly when tasks required him to make perceptual discriminations while indicating his response with a simple motor reply.

With respect to the various elements of attention, the patient’s initial encoding or registration of information seems to be intact. This inference can easily be made from his performances on immediate recall subtests. Most performances were solid, with the exception of immediate story recall which was quite poor. This suggests that as material became longer or more extensive, he was unable to consistently self-direct attentional resources. This finding of difficulty with the registration of more lengthy information is important because it has implications for classroom behavior. Given this finding, one would predict that listening to classroom discussions would be problematic for him, and that he would not initially register or “take in” the same range of information as his peers.

He had obvious difficulties with stimulus selection, response selection and inhibition, and with sustaining attention over time. Errors of omission on continuous performance tests were always elevated between the 7^{th} and 14^{th} PR. Simply put, this means that he frequently failed to identify stimulus presentations. He “missed” information. Errors of commission were between the 22^{nd} and 23^{rd} PR on continuous performance tests, and he performed between the 3^{rd} and 10^{th} PR on a competing programs go-no go task and on a subtest requiring him to maintain a posture while inhibiting extraneous movements and responses to orienting stimuli. Therefore, he was consistently unable to “not respond” to distracting influences and to prepotent, competing stimuli. Stimuli that should have evoked his response often did not, and stimuli that should not have elicited his response often did. He could not self-direct attentional resources by selecting appropriate stimuli and by inhibiting responding to distractions, so that attention was poorly focused and poorly controlled.

Shifting attentional focus from one thing to another was not a problem as manifest by an ordinary number of perseverative errors and responses on the WCST. He functioned at just about the same level as anyone else of his age within the general population within these parameters. However, overall WCST performance was poor, as will be discussed below.

Within the focus/execute dimension of attention, his performances were variable. This type of variability is always difficult to interpret because the functional neuroanatomies of the subtests within this dimension have never been clearly identified. The focus/execute dimension as Mirsky (1996) has defined it in general terms cannot be a monolithic entity because it is composed of different tasks. The tasks that comprise the category likely rely on different anatomic networks. Therefore, in combining the tasks together to form a “unitary” dimension, the most accurate and conservative inference that can be made is that he does not focus upon and execute novel tasks efficiently. New tasks with seemingly similar yet somewhat different demands can evoke “cognitive control” episodes that are manifest by his concentrating very hard and working more slowly than his peers. Insofar as the extra-test environment changes and is difficult to predict, one would expect this youngster’s functioning within the “real world” to be inconsistent and unpredictable. There is clear evidence for this conclusion on the basis of his “test taking” behavior during the course of the evaluation.

As might be predicted from such difficulty he experienced in the self-direction and control of attention, other aspects of executive functioning are affected. His Tower of London test performance could not be scored. This was because of his extremely numerous rule violations, which imply a disturbance in intention programs. His executive direction is characterized by a lack of self-control. When left to his own resources to determine the stimulus-based characteristics of novel situations, he cannot plan in order to solve problems. This implies he is highly dependent upon an external organization or structure, and this conclusion is supported by his performance on the WCST. He was initially slow to "catch-on" to what was required by discovering the initial category, with a performance that was between the 2^{nd} and 5^{th} PR. However, while he achieved 4 categories, only between the 6 to 10 PR, this occurred because of his significant failures to maintain set (since he achieved four of six categories, he discovered the three basic ideas, and it can be argued that if the test was longer, all six categories would have been achieved. His set failures influenced full category completion). He had obvious trouble in mentally tracking his performance. He would forget the principle he was applying as he was doing it, he would get distracted, lose his place, and make errors. Again, the data demonstrates he is unable to self-direct attention and concentration and is easily distracted, so that he needs a very "tightly organized" structure in order to appropriately stay "on task."

While his WMI individual subtest performances imply inconsistent working memory, this was also evident in the great variability in his Auditory Consonant Trigrams performance. Similarly, his WCST set failures can be understood as working memory failures. Design fluency performance at less than the 1st PR reveals he was unable to be productive on a task requiring him to self-generate activity, again revealing his deficit in fundamental self-direction. Therefore, executive functions are affected within dimensions of planning, working memory, and inhibition, all of which prevent him from appropriately initiating and maintaining self-directed activities. His intact "shifting" might actually be a manifestation of his distractibility. His ability to change the focus of or to shift attention actually reveals his inability to keep his mind on much of anything for very long.

Receptive language skills are intact. He performed at the expected mean level on a subtest requiring him to carry-out multiple step directions, so that basic language comprehension is unaffected. He has no difficulties in discriminating between or in reproducing novel speech sounds. Phonological processing was intact as inferred from his ability to delete sounds from words or to exchange sounds within words. However, rapid object naming was relatively low, only at the 25 PR, and this is a potentially important finding that can predict problems with reading fluency. In contrast, he had no difficulties retrieving words on his own. Therefore, any language difficulty he experiences is subtle and would likely be practically evident in reading.

He has no primary visual-perceptual-spatial information processing deficits. Object identification functions are intact as inferred from his error-free performance on a facial recognition task. He had no difficulties with object location functions as manifest by his respectable performance on the NEPSY Route Finding subtest. Constructional skills were intact as inferred from Design Copy and Block Design performances. Therefore, given these good performances, his extremely weak performance on Arrows likely occurred for reasons other than visual-perceptual-spatial deficit. This poor Arrows subtest performance may be a manifestation of difficulties in self-directing eye movements as a manifestation of frontostriatal abnormalities (Fan et al., 2005; Neggers et al., 2005; Silk et al., 2008), or perhaps an attempt at "solving" the task with a left-hemisphere information processing strategy, since a preponderance of his errors were from the left visual field. This does not appear to be a primary problem with analyzing left visual field input since he performed so well on most tasks requiring right-hemisphere information processing. These types of test score inconsistencies always need to be interpreted within the context of known brain-behavior relationships in order to make anatomic sense of inferences.

The mechanisms that support memory functions are intact. There is absolutely no evidence to demonstrate that he forgot anything he learned during the course of the evaluation. However, while the retention of new information is not an issue, his learning of new information represents an entirely different matter. The most obvious difficulty emerges from his performance on the CVLT-C. On a trial-by-trial basis, his learning was very inconsistent as indexed by free recall. He was able to recall information one time but then not the next time. The learning slope was therefore flat until trial five, when he was able to suddenly recall at least as much information as his peers. However, after a twenty minute delay, free recall was again poor, and he needed a recognition paradigm to identify what he knew because he could not remember it on his own. Therefore, he demonstrates a recall problem but not an information storage problem. He had difficulties with voluntary access, which is a finding that might be expected to correspond with complaints of forgetfulness or inconsistencies in learning. He never had difficulty in attempting to recall information on tasks that provided him with some sort of cueing or prompt. Once again, even his learning and memory test results demonstrate his reliance upon external structure. These aspects of the data also imply involvement of the frontostriatal system (see Chapter 9 in our book for a detailed discussion).

He did not perform well on any sensory-perceptual information processing task administered, on either hand. His poor finger discrimination scores are very difficult to interpret, since the findings are not lateralized and since there are no lateralizing cognitive deficits that would implicate brain regions surrounding somatosensory areas. Ability to perform imitation of hand positions follows a very skewed distribution, and he was continually inattentive to stimulus presentations. This inattention is the most likely reason for his poor performances on all sensory-perceptual tasks.

Motor speed on fingertip tapping tasks was unremarkable but this child demonstrated inconsistency in learning new motor sequences by touching one finger at a time in order. His performances on tasks of visuomotor precision were uniformly fast and inaccurate, demonstrating poor motor control. This again reveals his fundamental difficulties with self-directed processes. Against this background, it was surprising that he performed at the same level as his peers on a subtest requiring him to learn new motor programs. However, his acquisition in learning new programs was characterized qualitatively by difficulties with movement refinement, evidenced by changes in rate and rhythm, accompanied by pronounced force. Therefore, these motor findings might initially seem inconsistent, although qualitative observations imply subcortical involvement.

In terms of academic screening, his test data reveal difficulties with reading rate, as might be predicted on the basis of his relative slowness in object naming. His difficulties with reading comprehension are consistent with his variability in the initial encoding of information and inconsistency in working memory functions. There is no evidence of fundamental academic skills disorder, but application problems would be expected on the basis of his "executive control" deficits.

We chose this case for discussion for several reasons. It illustrates how to apply history to possible brain pathology. It also allows for linking presenting symptoms and behavioral observations to models of brain-behavior relationships while integrating cortical and subcortical systems. The test results were also interpreted within that framework of multiple systems. Once again, the data reveal the sensitivity of neuropsychological testing to brain-related pathology, while also demonstrating lack of specificity so that results are best described in cognitive and behavioral terms.

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