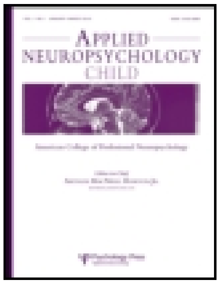

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Current models of cognition and behavioral diagnosis emphasize categorical classification over continuous considerations of function and promote the "differential diagnosis" of various conditions according to observational criteria. However, an overemphasis on a purely behavioral, categorical approach to understanding human function fails to address the comorbidity of different disorders and does not include a consideration of overlapping levels of function, from "pathological" through "normal," to "gifted" or exceptional. The frequent co-occurrence of "gifted" and "pathological" function is thus difficult to understand from a corticocentric and purely behavioral and observational point of view. This article reviews "giftedness" in relation to the diagnosis of attention-deficit hyperactivity disorder, coexistence of which is termed "twice exceptional." It additionally considers problems in assessing these functions using current neuropsychological tests and methodologies that are presumably based upon a corticocentric model of cognition.

Key words: *ADHD, expertise, giftedness, intelligence*

INTRODUCTION

"Twice exceptional" is a term used to describe high-ability or "gifted" children with learning disabilities, autism spectrum disorder, and/or attention-deficit hyperactivity disorder (ADHD). Although the concept of "twice exceptional" function is increasingly common within and outside of neuropsychology, disagreement remains about how to define giftedness and what constitutes the defining factors of learning and attentional disorders. ADHD is most effectively described as representing trouble with intention formation and execution and with problems adapting behavior to environmental demands (Denckla, 1992). Some would posit that ADHD does not occur in "gifted" children, or that gifted individuals are "misdiagnosed" with ADHD due to aspects of giftedness itself (Antshel et al., 2007; J. T. Webb et al., 2005). Yet such reasoning is frustratingly circular and does not account for the many "gifted" individuals who are able to get things done effectively.

Perhaps such arguments arise as a function of challenges reconciling two such apparently contradictory states—gifted, yet unable to reliably generate adaptive behavior in context—from the corticocentric and behavioral diagnostic vantage point that has dominated neuropsychology and psychiatry. As we have discussed previously, corticocentric approaches to function have been particularly problematic in relation to understanding neurodevelopment (Koziol & Budding, 2009; Koziol, Budding, & Chidekel, 2010). Although ostensibly placed within an evolutionary context, corticocentric models nevertheless unwittingly echo the

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problems posed by creationist views by failing to place human function fully within a developmental context. If ontology recapitulates phylogeny, the corticocentric view *must* be incorrect. Models that incorporate brain-wide systems and integrate the functions of the cortex, basal ganglia, and cerebellum better ensure biological continuity in considering human function (Tomasi & Volkow, 2011). A corticocentric bias precludes consideration of the procedural as well as the declarative contributions to human adaptive function that brain-wide models include. Behavioral approaches are strictly observational and do not take brain–behavior relationships or functional neuroanatomy into account. These are limiting factors in understanding exceptional behaviors and those associated with poor follow-through and have precluded understanding of the co-occurrence of the same.

Our current conception builds upon work first done by Doya (1999) and expanded upon by Cotterill (2001). In a previous article, we, along with Leonard Koziol, presented an updated, integrated model of gifted function in which we viewed expertise and giftedness within the context of general adaptation (Koziol et al., 2010). In this article, we will discuss the challenges of considering the diagnosis of ADHD within the context of high intelligence and some of the ways in which a dual-tiered perspective that incorporates both cortical and subcortical functions can explain their coexistence.

ADHD: CATEGORICAL BEHAVIORAL DIAGNOSIS VERSUS DIMENSIONAL GRADATION

According to the current *Diagnostic and Statistical Manual of Mental Disorders*-Fourth Edition, Text Revision (DSM), a diagnosis of ADHD is made if an individual meets certain behavioral criteria (American Psychiatric Association, 2000). The diagnosis is differentiated into three subtypes based on the relative number of symptoms across dimensions of inattention/disorganization, hyperactivity, and impulsivity. These categories are used quantitatively and often dichotomously and are based solely upon observable behavior. Given the dichotomous nature of this approach, the high comorbidity between ADHD and other neurodevelopmental disorders has been underappreciated and insufficiently understood (Felling & Singer, 2011; Rommelse et al., 2009; Takeda, Ambrosini, deBerardinis, & Elia, 2012). Fortunately, recent discussions about ADHD have more directly addressed the heterogeneity of the disorder. The greater the heterogeneity, however, the less useful the diagnosis (Fair, Bathula, Nikolas, & Nigg, 2012; Valo & Tannock, 2010). In an eloquent review of the problems associated with the DSM-based categorical classification of psychiatric and developmental disorders, Hyman (2010) argues for a shift toward a more dimensional approach to psychopathology. He observes, "In the case of the DSM system and its progeny, the unintended reification of diagnostic entities is facilitated by the lack of a developed scientific base, combined with the wide embrace of a classification system developed, above all, to foster inter-rater reliability" (p. 159). He asserts, "For many domains of psychopathology, such as depression or ADHD, dimensional approaches will likely capture clinical and research data far more effectively than do current categorical approaches" (p. 171). However, whether it is considered categorically or dimensionally, the current diagnosis of ADHD continues to be based on behavioral criteria, while the relationship of behaviors to specific brain areas or functions is underemphasized.

DEFINITIONS OF GIFTEDNESS

There is no single definition of giftedness. While some posit that giftedness is defined by a high IQ score, we have argued that the coexistence of expertise in the absence of high—or even average—"intelligence" as measured by IQ tests highlights but one of the limitations of such tests and the associated "g" factor that they purport to measure (Koziol et al., 2010; Lezak & Loring, 2004). Although a number of authorities have increasingly argued against general intelligence, or "g" as a measure of giftedness, and in favor of a more nuanced and multidimensional approach (Sternberg, 2010; Subotnik, Olszewski-Kubilius, & Worrell, 2011), McClain and Pfeiffer (2012) recently completed a national survey that found that the majority of states within the United States rely primarily, if not exclusively, on IQ test scores to define and determine whether a student is considered gifted. Defining "giftedness" in this way seems to serve the purpose of qualifying a child for an advanced educational program. Similarly, current neuroscientific and neuropsychological investigations of gifted function generally use IQ-based cutoff scores (usually Full-Scale IQ ≥ 120) as a determination of giftedness. According to N. E. Webb (2011), "gifted refers to individuals functioning in the top 3–5% in the nation on objective, standardized measures or to individuals performing at an elite level in specific, recognized domains such as music. Giftedness refers to a series of particular talents and abilities that are not evenly distributed" (p. 1085). This implies that "giftedness" can occur outside of the domain of general intellectual ability, which is consistent with Winner's definition of giftedness on which we have relied. Winner (1996) operationalizes three defining characteristics of giftedness: early and rapid domain mastery, independent acquisition of domain expertise, and intrinsic self-motivation or ''rage to master'' (Koziol et al., 2010). According to these criteria, giftedness can occur apart from high IQ, and high IQ can occur outside of the context of giftedness. This definition is similar to that offered by the National Association for Gifted Children, which defines gifted children as ''those who demonstrate outstanding levels of aptitude (defined as an exceptional ability to reason and learn) or competence (documented performance or achievement in top 10% or rarer) in one or more domains. Domains include any structured area of activity with its own symbol system (e.g., mathematics, music, language) and/or set of sensorimotor skills (e.g., painting, dance, sports)'' (National Association for Gifted Children, 2010). Although these criteria are observational, they are unambiguous.

The Aurora Battery has recently been developed to assess giftedness from a more nuanced perspective, which does not incorporate traditional IQ measures. It is based on Sternberg's theory of successful intelligence, which views intelligence as a balanced system of abilities that allows one to adapt to, shape, and select environments to accomplish one's goals, within the context of one's culture or society (Kornilov, Tan, Elliott, Sternberg, & Grigorenko, 2012; Sternberg, 1999; Sternberg & Kaufman, 1998). In this model, analytical, creative, and practical abilities play independent—though related—roles in intellectual functioning and associated successful lifetime adaptation. People with successful intelligence use creative abilities to generate new ideas and cope with relative novelty, analytical abilities to ascertain the value of their new ideas and coping strategies, and practical abilities to put their ideas into practice and to persuade others of the value of those ideas (Kornilov et al., 2012). Following this model, the Aurora Battery is composed of a set of assessments that evaluate analytical, creative, and practical abilities in a group or classroom setting. Tasks are designed to define a person's strengths in original and flexible thinking, as well as the knowledge and abilities on which he or she can call in everyday life situations, which are designed to map onto abilities that relate to real-world innovation. The skill(s) sets measured likely correlate with aspects of executive function, but test developers have not specified any brain–behavior relationships. Doing so will be an important step to ensuring the usefulness of the battery. We have discussed the brain–behavior relationships of several aspects of giftedness and executive function from a dual-tiered cognitive perspective that encompasses episodes of automatic behavior alternating with episodes of higher-order cognitive control (Koziol, Budding, & Chidekel, 2011), and we believe that this perspective should be referenced in this enterprise (see Koziol et al., 2010).

ADHD DIAGNOSIS IN THE CONTEXT OF HIGH IQ

Most published studies of children and adults diagnosed with ADHD employ subjects with average IQ; in fact, most studies of *all* types appear to employ individuals with average IQ, unless they are specifically looking at IQ as a variable. There are many ''myths'' associated with ADHD (Barkley, 2006), and among them is the idea that people with ADHD have higher-than-average IQs compared with the larger population. In fact, it has been more common to find somewhat lower-than-average IQs among children with ADHD. In a meta-analysis of 137 ADHD studies conducted between 1980 and 2002, Frazier and colleagues found that individuals diagnosed with ADHD had overall an approximately 9-point lower IQ score than those without the diagnosis (Frazier, Demaree, & Youngstrom, 2004). It would seem more likely that inattention and hyperactivity would negatively affect intelligence test scores in *all* children, regardless of whether they have diagnosable ADHD symptoms (Antshel et al., 2007). Yet, longitudinal studies by Antshel and colleagues demonstrate that the ADHD diagnosis is valid among high-IQ children and that ADHD symptoms in this population should not be dismissed as reflecting ''boredom'' or other epiphenomena that have been associated with high IQ (Antshel, 2008; Antshel et al., 2007; Antshel, Hendricks, et al., 2011). ADHD and its association with executive function deficits are similar among children with high, average, and low IQ, which renders diagnosis and treatment relevant for all children (Katusic et al., 2011). Katusic and colleagues found that high IQ can favorably mediate some outcomes such as reading achievement levels, but this does not obviate the need to treat the symptoms of ADHD in high-IQ children.

Antshel and colleagues recently reviewed studies that addressed possible misdiagnosis or overidentification of ADHD in gifted students, particularly in the context of purported ''overexcitabilities'' demonstrated by gifted children (Antshel, Hendricks, Faraone, & Gordon, 2011; Dabrowski, 1966; Piechowski & Colangelo, 1984). The authors assert that much of the debate regarding the coexistence of ADHD and high IQ has unfolded around the issue of potential symptom overlap, while it has not focused on whether symptoms cause impairment. They stress that high IQ is a relevant factor only to the degree that it may impact the onset or staging of the functional impairment required to make an ADHD diagnosis, but superior cognitive ability does not appear to protect highly impulsive people from the full range of impairments associated with impulsivity. The authors conclude that concerns about misdiagnosing gifted children with ADHD are unfounded so long as the clinical focus is on impairment and not simply on the presence of high energy and activity.

THE NEUROLOGY OF GIFTEDNESS AND THE ROLES OF THE CORTEX, BASAL GANGLIA, AND CEREBELLUM

We have discussed in detail the roles that the cortex, basal ganglia, and cerebellum play in relation to adaptive behavior in general and in relation to "gifted" behaviors and function more specifically (Koziol & Budding, 2009; Koziol et al., 2010). We reviewed a study of cortical development by Shaw and colleagues (2006) that found that more intelligent children exhibited an earlier acceleration and a prolonged phase of cortical increase, culminating in vigorous cortical *thinning* by early adolescence, with patterns of dynamic change most prominent in the prefrontal cortex. We also reviewed the work of Tau and Peterson (2010), who observed that along with the cortical thinning process, which proceeds "back to front," the perisylvian cortices in inferior parietal and posterior temporal areas and in the left hemisphere appear to thicken between childhood and adulthood. More importantly for our current purposes, we noted that excessive thinning was found to be associated with psychiatric disorders such as schizophrenia, while slowed thickening was found to be associated with ADHD. In addition, the pattern of delayed cortical thickening within the prefrontal lobes is similar in both those diagnosed with ADHD and in high-IQ children. This suggests a neurobiologic underpinning for certain symptoms and behaviors that can "overlap" both ADHD and giftedness.

Children with ADHD and children with superior IQ have greater delays in the maturation of their prefrontal cortices compared with non-ADHD or average-IQ age-matched peers (see previous paragraph). An overall delay in the maturation of the prefrontal cortex is not a biological accident, and it might serve the purpose of developing flexible, broad thinking (Chrysikou, Novick, Trueswell, & Thompson-Schill, 2011). The limited control over thinking and behavior implicated by delayed prefrontal maturation might foster the development of creativity. In ADHD and/or gifted populations, this delay in maturation might be associated not only with creativity but also with the delayed development of social skills that is often characteristic of these populations.

Expanding the consideration of brain systems in this manner allows us to expand our understanding of ADHD to see it more broadly than as a manifestation of isolated "frontal lobe" impairment. Advances in neuroimaging techniques have implicated a number of different brain abnormalities associated with ADHD (Vaidya, 2011). Nevertheless, this delayed maturation, associated with less cognitive and behavioral control, is often characteristic of disturbances within a variety of executive functions.

We also reviewed the important roles played by the basal ganglia and associated cortico-striatal intention programs in relation to several essential features of giftedness, as defined by Winner. To summarize, intention programs include knowing when to start a behavior, knowing when not to start a behavior, knowing when to persist with a behavior, and knowing when to stop a behavior. The intrinsic motivation toward mastery and the obsessive interest in the domains gifted individuals pursue implied an overfocused, *perseverative* attention that was resistant to distraction. Within this circuitry, we associated the particular importance of the nucleus accumbens, a critical reward/reinforcement center located within the basal forebrain (Heimer, Van Hoesen, Trimble, & Zahm, 2008), with the "rage to master," seen in gifted children. We highlighted the finding that the striatal direct pathways are functionally matured in childhood, while the indirect pathways are immature in young children and reach adult levels in approximately the middle of the second decade (Segawa, 2000). We proposed that the multiple white matter connections between cortex and basal ganglia, which are greater in gifted children, would support this level of activity and the resulting extreme behavior. We noted that functions transacted in circuits that connect the cerebellum with this "limbic striatum" would also contribute to exaggerating the "force" of the motivation (Bava et al., 2010; Bostan & Strick, 2010; Ullen, Forsman, Blom, Karabanov, & Madison, 2008).

We additionally explored the importance of cerebellar forward and inverse models for gifted function. While the basal ganglia can be understood as a "reward" and inhibitory control region, the cerebellum can be considered the brain's behavioral refinement mechanism (Koziol & Budding, 2009; Koziol et al., 2010). We examined the processes by which a motor program is selected through frontal-striatal interactions, with the neural signals comprising this program then relayed to the cerebellum through the mossy fiber input system to establish a cerebellar "model" of what the brain has decided to do. We linked the processes associated with cerebellar forward and inverse models to the important role of automaticity and increased processing speed for efficient function (Haruno, Wolpert, & Kawato, 1999; Saling & Phillips, 2007). It is important to remember that higher-order control associated with cortical sensory processing works slowly, and the brain cannot rely upon cortical sensory feedback to guide behavior if an individual is to be effective in adapting to the environment (see Koziol, Budding, & Chidekel [2010, p. 510] for our previous example of reaching for a coffee cup remains salient here, as an illustration of an automatic behavior established through practice and anticipation). We highlighted how the cerebellum "speeds up" information processing by constructing models based upon anticipation instead of direct sensory feedback, while honing, timing, and fine-tuning the efficiency of that behavior as it is successfully repeated.

ADHD AND GIFTEDNESS: SYMPTOMS AS PROBLEMS WITH ADAPTIVE BEHAVIOR IN CONTEXT

The purpose of an organism is to survive. All organisms exist in the context of an environment, and to survive, they must interact with that environment. When an organism interacts successfully, we describe that process and its outcome as adaptation. Organisms that cannot adapt do not survive. All humans and other vertebrate organisms depend upon foundational sensory and motor capacities to interact successfully with and adapt to the environment.

Sensory capacities enable us to identify, recognize, and locate objects. Motor abilities and intention programs enable us to know *what* to do in relation to what we perceive, to know *how* to act (program the behavior), and to know *when* to act (do it; Heilman & Rothi, 2003). To accomplish these functions, the vertebrate brain is organized to allow a division of labor between the left and right cerebral hemispheres and between anterior and posterior cortices. The left hemisphere was first specialized for the control of routine, frequently performed patterns of behavior under familiar, predictable circumstances (Macneilage, Rogers, & Vallortigara, 2009); within this context, we include language as a specialized instance of routinization (Podell, Lovell, & Goldberg, 2001). The right hemisphere was first specialized to detect and respond to unexpected stimuli within the environment and to problem-solve in relation to novel or unfamiliar circumstances.

Having areas of the brain specialized to accommodate and respond to familiar versus novel demands provides the decisive adaptive advantage in interacting with a changing and complex environment (Toates, 2006). Unfamiliar experiences and our behavioral responses to them become familiar and routine with repeated exposure. With enough repetition, some responses become "automatic." Automatic behaviors are adaptive, efficient, and economical in that they "free up" the cerebral cortex to process and analyze more novelty. While we execute most daily tasks automatically, we need to be able to alter a routine if something changes within the environment that renders the routine behavior inappropriate or maladaptive. The capacity to "switch" between releasing routine behavior and engaging higher-order reasoning is critical for adaptation. Switching depends upon fine-tuned interactions between frontal cortical-basal ganglia networks (Hikosaka & Isoda, 2010). This dual-tier system allows us to use what we know and to benefit from experience in interacting with the environment.

The gifted may be able to identify the stimulus-based characteristics of problems more quickly and even intuitively for the purpose of effective, efficient problem-solving (Shavinina & Seeratan, 2004). But if we consider the important problems in adaptation demonstrated by children with ADHD, we might surmise that a gifted child with ADHD might not translate the quick identification of critical information into effective behavioral responses to this knowledge. The behaviors of children with ADHD can reflect pathology within all four of the brain's intention programs: knowing when to act, knowing when not to act, knowing when to keep an action going, and knowing when not to keep an action going. A gifted child with ADHD will encounter problems in these functions characterized or even amplified by his or her greater knowledge base and the quick pace at which information impinges on him or her. Brown and colleagues demonstrated that high-IQ children, despite their cognitive strengths, tend to suffer from significant impairments in these types of "executive functions" and that these impairments are significantly greater than what is observed within the general population (Brown, Reichel, & Quinlan, 2011).

Problems knowing *when not to act* are manifest in impulsive behavior. It follows that children with ADHD act impulsively, at inappropriate times. While a child with ADHD may interrupt others and blurt out answers to questions, a gifted child may do this even more often, given a larger fund of information on which to call. Problems not knowing *when to stop* a behavior drive the persistence of such maladaptive behavior, irrespective of the negative feedback it generates. This can be more impairing in gifted children, as it is intensified by a "rage to master." Recall that direct pathway function (Do it!) matures before indirect pathway function (Don't do it!) in the best of circumstances and that prefrontal areas are thought to mature more slowly among children with ADHD and very high IQ (see above "thickening" reference). Difficulty knowing *when to act* can be seen in episodes of procrastination and apathy toward activities that are not inherently rewarding, while problems knowing *when not to stop* may manifest in a lack of persistence on such tasks once they have been initiated and in a propensity to lose focus and stray "off task." People with ADHD are challenged to adapt behavior to environmental demands. Behavior needs to be generated at the right time with an appropriate level of intensity, which is defined as not too little and not too much, according to context. The ''rage to master'' in gifted children can be construed as being composed of persistent and intense focus on an area of interest, coupled with trouble inhibiting these behaviors when environmental demands change and necessitate they shift focus and sustain ample effort to complete a less rewarding activity. As can be seen, people diagnosed with ADHD, as well as ''gifted'' children, can share the same disturbances in the brain's ''intention'' and ''refinement'' programs, and their deficits may be driven by the same neurobiologic mechanisms.

LIMITATIONS OF NEUROPSYCHOLOGICAL TESTING FOR EVALUATING ADAPTIVE CHALLENGES ASSOCIATED WITH ADHD WITH OR WITHOUT 'GIFTEDNESS'

Neuropsychological tests, conceived through the corticocentric model that has dominated neuropsychology, do an incomplete job of measuring many of the capacities that are at the heart of attentional disorders. Most neuropsychological tests go through dorsolateral cognitive channels and do not directly measure medial circuitries (Malloy & Richardson, 2001). Knowing when to act—or initiative—is not readily objectively measured. And although some continuous performance tests provide a measure of the capacity to know when not to act—or impulsivity as measured by ''commission'' errors—the paradigms that inform them differ and not all are equally sensitive. Similarly, these different paradigms do not share the same neurologic underpinnings (see Koziol & Budding, 2009, for a review). Go-no go procedures can be useful measures of impulse control, but many neuropsychologists do not seem to use them. Sustained attention—knowing when to keep an action going—can be measured by continuous performance tests and by set-loss errors on tasks of different types. Knowing when not to keep a behavior going—or the ability to shift attention—can be measured by procedures like the Wisconsin Card-Sorting Task. However, while there are a variety of other ''cognitive shifting'' tasks, their relationships to ADHD, giftedness, and the underlying neuroanatomies that drive them have not been systematically studied and are unknown. Generally speaking, as Lezak and Loring (2004) remind us, neuropsychological tests have little ''face validity'' and often do not measure what the name of the test implies.

This represents a limited repertoire to measure such foundational capacities. At the same time, many of these tasks may be ''too easy'' to allow them to discriminate problems in gifted people with ADHD, while clinicians may fail to recognize the need for normative information from this population (Denckla, 1994). Of equal if not greater importance than the dearth of tests available to measure these critical aspects of intention programs, there is no test or methodology that measures how effectively an individual is able to establish and access procedural and automatic information. Although adaptive function depends upon the ability to develop expertise with increased exposure, when this phenomenon is considered at all in psychometrics, it is described pejoratively as a ''practice effect'' and is viewed only as a potential confounding variable to the validity of scores when the same test is readministered before a proscribed interval of time has passed.

Difficulty making procedures and accessing them at the right time is at the heart of attentional disorders. A subset of the gifted may have relative difficulty with the latter while the former comes easily to them. Developing measures sensitive to these capacities will be important to increase the clinical utility of testing attentional function in general, while such measures may provide particular insight into the function of gifted populations with attentional disturbances.

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